TITLE PAGE

INTRODUCTION TO ORBITAL MECHANICS

AND RENDEZVOUS TECHNIQUES

TEXT 1

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PREFACE

The SPACE NAVIGATION AND ORBITAL MECHANICS COURSE is divided into three volumes:

INTRODUCTION TO SPACE NAVIGATION

INTRODUCTION TO ORBITAL MECHANICS AND RENDEZVOUS TECHNIQUES

APPLIED ORBITAL MECHANICS

Each volume consists of one or more programed instruction texts. Each text contains a list of prerequisites and a list of objectives.

The prerequisites tell you what you should already know before you begin the first section of programed instruction material. If you cannot meet the prerequisites, you will find it very difficult to proceed through the text.

The objectives tell you what you will be able to do upon completion of the text, i.e., the objectives tell you what problems you'll be able to solve, what items you'll be able to define, etc. If you can satisfy the objectives without reading the text, proceed to the next text.

This text is yours to keep. You may want to write, sketch or underline in it. The more you participate, the more you will learn and the longer you will remember what you learn. Should you wish to review the text in a year or so, your notes would be quite valuable in refreshing your memory.

INTRODUCTION

This is Text 1 of Volume 2 of the SPACE NAVIGATION AND ORBITAL MECHANICS course.

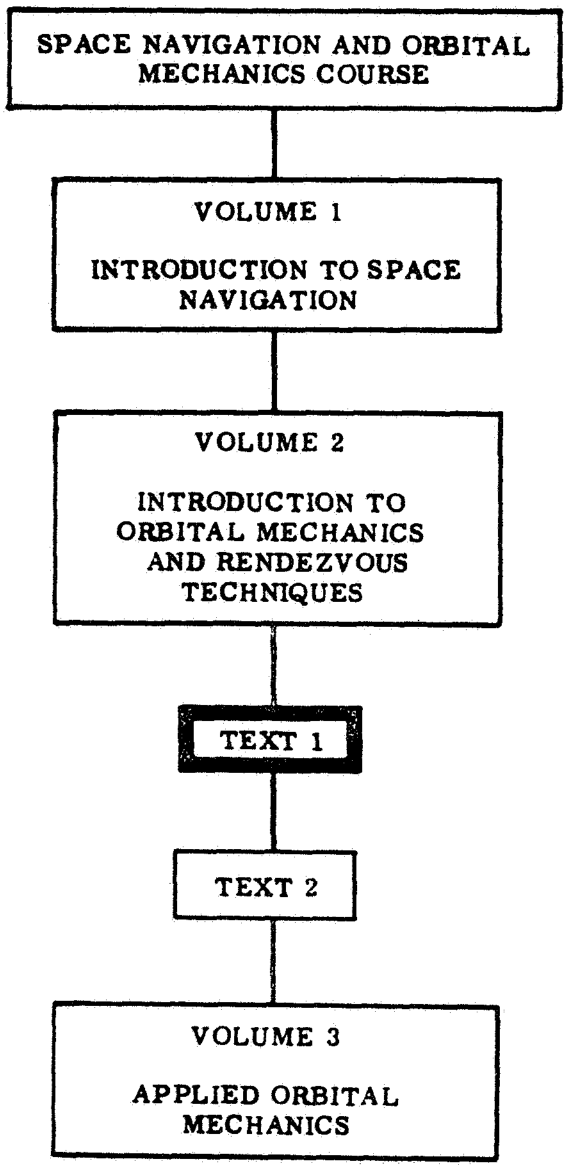
This text contains the following sections:

SECTION 1: THE LAUNCH

SECTION 2: INSERTION INTO ORBIT

Section 1 covers the spacecraft launch and the resulting ground tracks. Section 2 covers the actual insertion into orbit and the characteristics of the resulting orbits.

The drawing below shows how this text fits into the SPACE NAVIGATION AND ORBITAL MECHANICS course.



PREREQUISITES

Before starting this text, you should have successfully completed volume 1 of the space navigation and orbital mechanics course, INTRODUCTION TO SPACE NAVIGATION, Texts 1, 2, and 3 or their equivalent.

OBJECTIVES

Upon completion of this text, you will be able to do the following:

1. Given an appropriate illustration of an orbit or ground track, identify the following items:

   A. launch azimuth angle
   B. orbital inclination
   C. true anomaly
   D. heading angle
   E. flight path angle
   F. insertion angle

2. Given a launch site location and launch azimuth angle, sketch the approximate ground track.

3. Given an insertion point, insertion angle, and insertion velocity relative to circular velocity, determine the approximate locations of apogee and perigee and the true anomaly of the insertion point.

4. Given the true anomaly of a spacecraft, determine its location with respect to apogee and perigee and whether its flight path angle is positive, negative, or zero and vice versa.

5. Given a launch site latitude, determine:

   A. the minimum and maximum orbital inclinations which can be achieved and the launch angles necessary to achieve them.
   B. the approximate launch azimuth angles required to achieve a given orbital inclination.

6. Given a list of flight path angle characteristics, identify those applying to a circular orbit.

DIRECTIONS FOR USING TEXT

The majority of frames in this text each have one or more questions. The answers to these questions always appear in the beginning of the following frame.

Basically, there are two types of questions used. The first is used with "lecture" frames; i.e., frames which present complete units of information or concepts. This type of question tests your comprehension of the material in that frame.

The other type of question is used with frames in which the information or concept is intentionally left incomplete. In these frames, the student is required to use whatever information he is given (either in the text of the frame or an illustration referenced from the frame) to answer the question. The answer to this question, then, completes the concept or unit of information presented in the frame.

INSTRUCTIONS

1) READ THE FRAME MATERIAL

2) ANSWER THE QUESTIONS IN THAT FRAME

3) CONFIRM YOUR ANSWERS AND REVIEW THE FRAME MATERIAL IF NECESSARY

4) REPEAT STEPS 1, 2, AND 3 UNTIL A SECTION IS COMPLETED

5) ANSWER ALL REVIEW QUESTIONS

6) CONFIRM REVIEW QUESTION ANSWERS

7) REVIEW THE ITEMS YOU HAVE INCORRECTLY ANSWERED UNTIL YOU HAVE MASTERED THE MATERIAL IN THAT SECTION

8) PROCEED TO THE NEXT SECTION

SECTION 1

THE LAUNCH

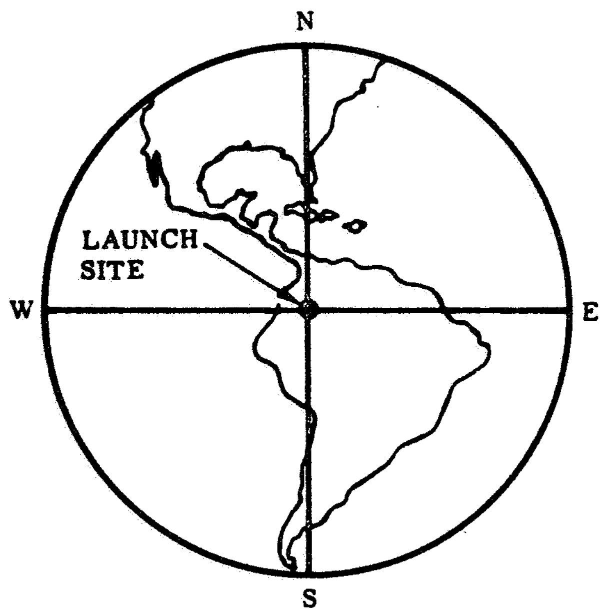


FIGURE 1-1

1-1	

In Volume 1 of this series, we said that the minimum orbital inclination that can be achieved from a given launch site is equal to the latitude of that launch site. Now we are going to look into this a little more closely and see why it is true and just how the minimum inclination is achieved.

To start with, we will use a hypothetical launch site on the equator, as shown in figure 1-1.

1. From an equatorial launch site, the minimum orbital inclination that could be achieved is________________degrees.

1-2	

ANS-1: 0

The plane of such an orbit would, of course, coincide with Earth's equatorial plane.

2. To achieve this zero-degree orbit, the spacecraft would have to be launched in what direction? ____________________

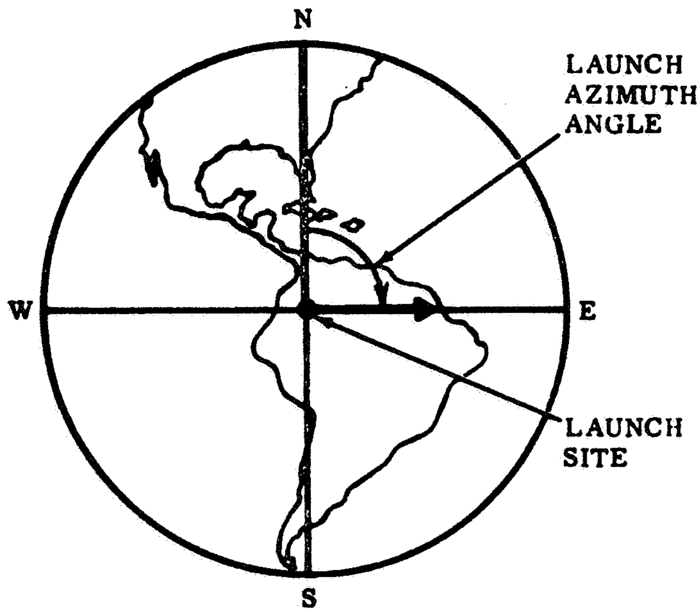


FIGURE 1-2

ANS-2: east

Actually, it could also be launched west, but we would normally take advantage of Earth's rotational speed by launching east

To define the direction of launch more explicitly, the term launch azimuth angle is used. The launch azimuth angle, illustrated in figure 1-2, is the angle between due north and the direction in which the spacecraft is launched.

3. The launch azimuth angle in question 2 was ____________ .

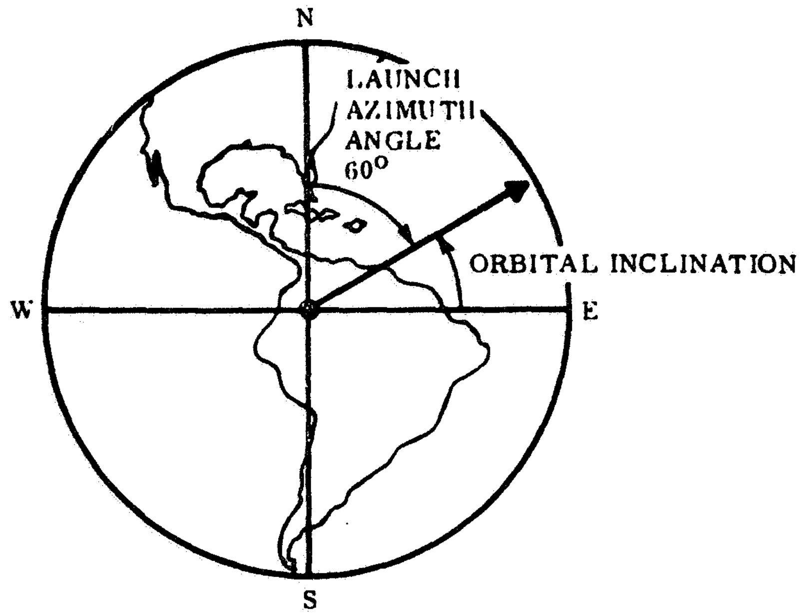


FIGURE 1-3

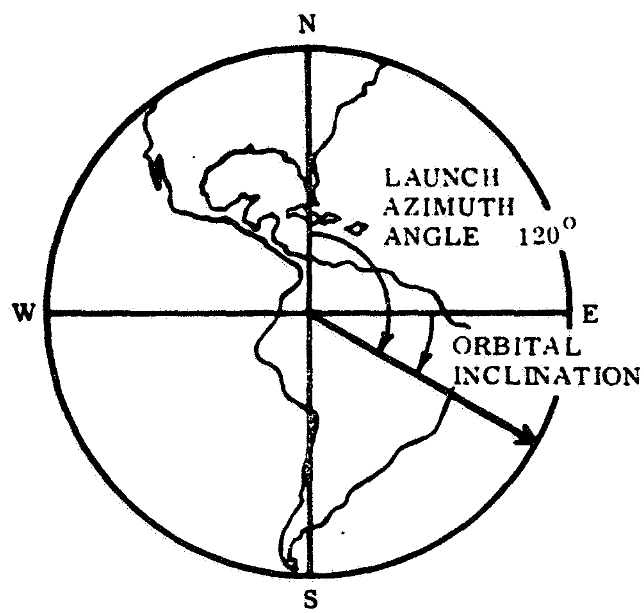


FIGURE 1-4

1-4	

ANS-3: 90°

Thus, for an equatorial launch site, minimum orbital inclination is achieved by a launch azimuth angle of 90°. Any other launch azimuth angle -- either greater or smaller than 90° -- will obviously tilt the orbit so it no longer coincides with the equatorial plane.

4. For example, if the launch azimuth angle were equal to 60°, as shown in figure 1-3, the resulting orbital inclination would be __________ degrees.

1-5	

ANS-4. 30

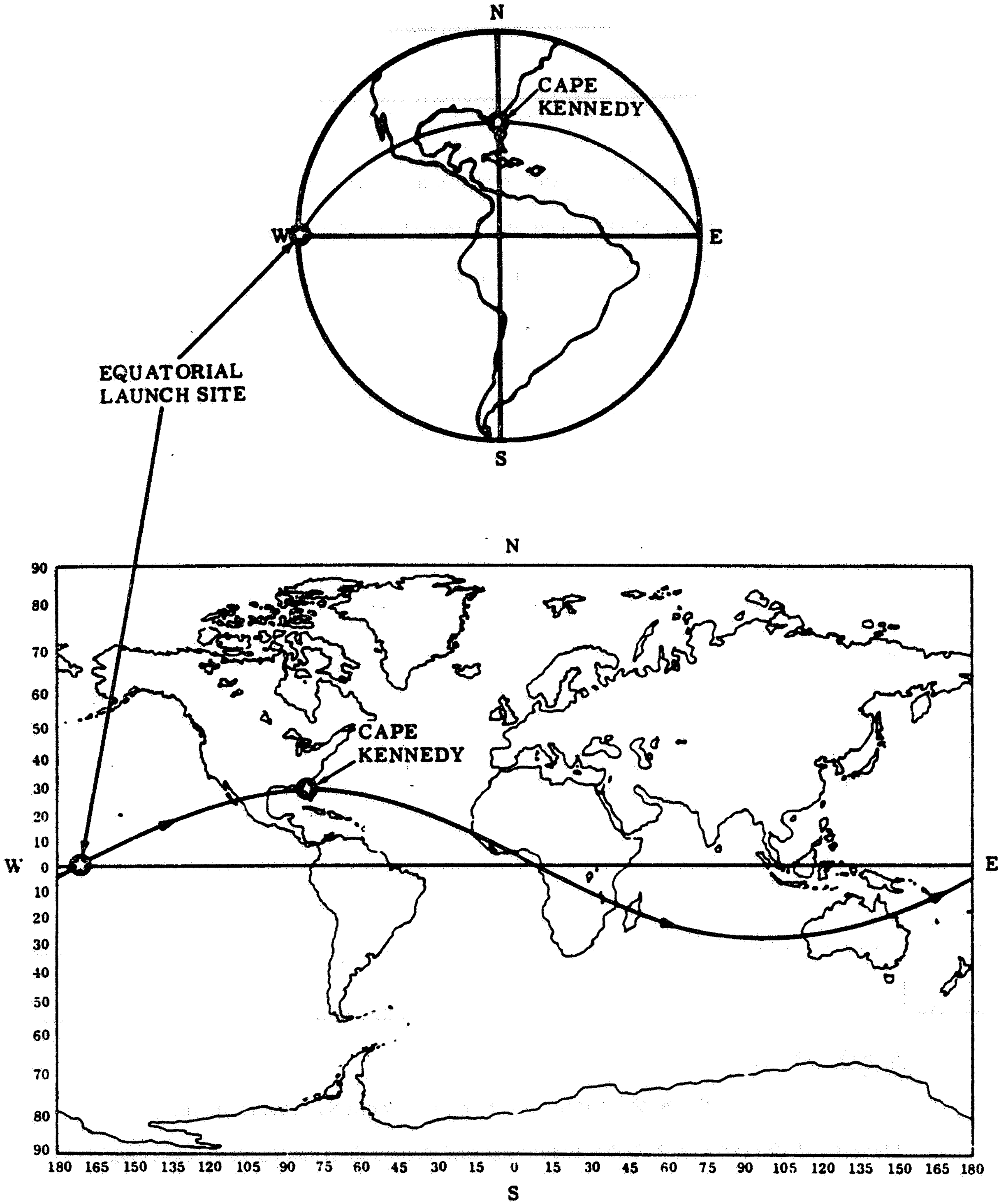
As you can see from figure 1-3, the orbital inclination is equal to the difference between 90° and the launch azimuth angle. In this case, it is $90 - 60 = 30$.

5. Suppose the launch azimuth angle was 120°, as shown in figure 1-4. What would be the inclination of the resulting orbit? __________

1-6	

ANS-5: 30°

The inclination would be the same as for the 60° launch azimuth angle. The only difference is that the ascending and descending nodes are reversed.



N
CAPE
KENNEDY
W
E
S
EQUATORIAL
LAUNCH SITE
N
CAPE
KENNEDY
W
E
S
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
180 165 150 135 120 105 90 75 60 45 30 15 0 15 30 45 60 75 90 105 120 135 150 165 180

FIGURE 1-5

1-7

All very simple, as long as we keep the launch site on the equator. Unfortunately, our chief real-life launch site is Cape Kennedy, which is at almost 30° north latitude. ($28\ 1/2^{\circ}$, to be exact, but we can round it off to 30° for our purposes.) Before we panic, however, let's take a look at the path of a spacecraft that was launched from an equatorial site into an orbit with an inclination of 30°. This path is shown in two forms in figure 1-5. (Note: We are ignoring Earth's rotation for the time being, so don't worry about the fact that the ground track in figure 1-5 is 360° of longitude from one ascending node to the next.)

6. As we learned in Volume 1, a spacecraft in an orbit inclined 30° with respect to the equatorial plane will reach a maximum north and south latitude of ____________________.

1-8

ANS-6: 30°

A spacecraft in a 30° orbit, then, would pass over the latitude of Cape Kennedy at the most northerly point of its orbit. In fact, if we select the launch site correctly, as we did in figure 1-5, the spacecraft will pass over Cape Kennedy itself. Notice, however, the direction the spacecraft is traveling at the northernmost and southernmost points of the ground track.

7. At 30° north and 30° south, the spacecraft is traveling directly ________________.

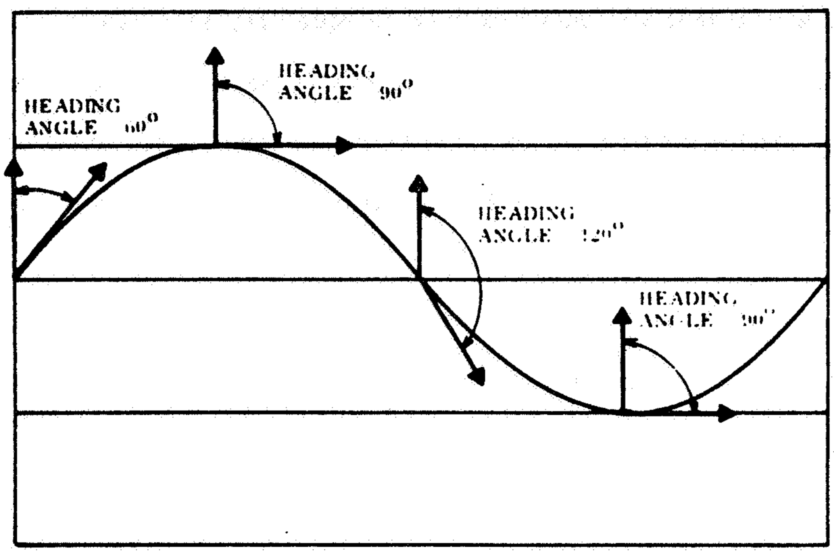

HEADING
ANGLE 60°
HEADING
ANGLE 90°
HEADING
ANGLE 120°
HEADING
ANGLE 90°

FIGURE 1-6

1-9

<u>ANS-7:</u> east

This direction of travel is defined more specifically by the <u>heading</u> <u>angle.</u> The heading angle is measured in the same way as the launch azimuth angle, i.e., from due north to the direction of travel. (See figure 1-6.)

8. The heading angle of the spacecraft as it passes over Cape Kennedy would be ______________.

1-10

<u>ANS-8:</u> 90°

9. To launch a spacecraft into the same 30° orbit from Cape Kennedy at 30° latitude, what launch azimuth angle would be required? ________________

1-11

<u>ANS-9:</u> 90°

The launch azimuth angle can be thought of as the spacecraft's heading angle at the time of launch.

10. If the orbit were inclined 50°, you expect the heading angle at the northernmost point of the ground track to be __________ degrees.

1-12

<u>ANS-10:</u> 90

In fact, the heading angle of any orbit will be 90° at its northernmost and southernmost points.

11. Launching a spacecraft from a latitude of 60° south at a launch azimuth angle of 90° would produce an orbit with an inclination of _______________.

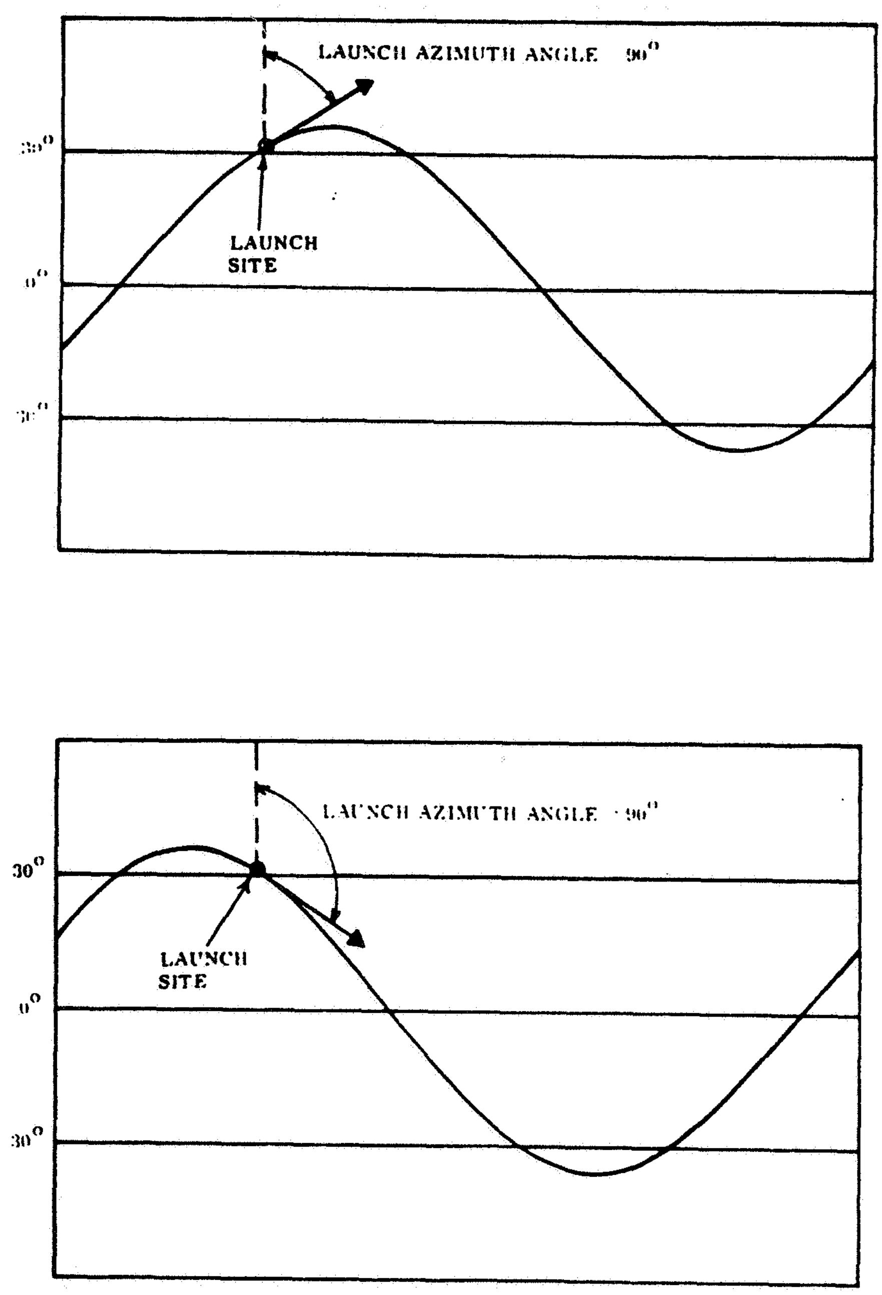

LAUNCH AZIMUTH ANGLE 90°
30°
LAUNCH
SITE
0°
30°
LAUNCH AZIMUTH ANGLE 90°
30°
LAUNCH
SITE
0°
30°

FIGURE 1-7

1-13	

ANS-11: 60°

So, a launch azimuth angle of 90° produces an orbit with an inclination equal to the latitude of the launch site.

But what about launch azimuth angles other than 90°? The results of varying the launch azimuth angle are shown in figure 1-7.

12. A launch azimuth angle greater than 90° produces an orbit with an inclination ______________ (greater/less) than the launch site latitude. A launch azimuth angle less than 90° produces an orbit with an inclination __________ (greater/less) than the launch site latitude.

1-14	

ANS-12: greater

greater

No matter which way we turn the spacecraft, the inclination increases, which simply shows that, as we said earlier, the minimum orbital inclination that can be achieved from a given launch site is equal to the latitude of that launch site.

The maximum inclination, however, is another matter.

13. Launching either straight north or straight south (launch azimuth angle equal to 0° or 180°, respectively) from any latitude would produce an orbit with an inclination of ______________.

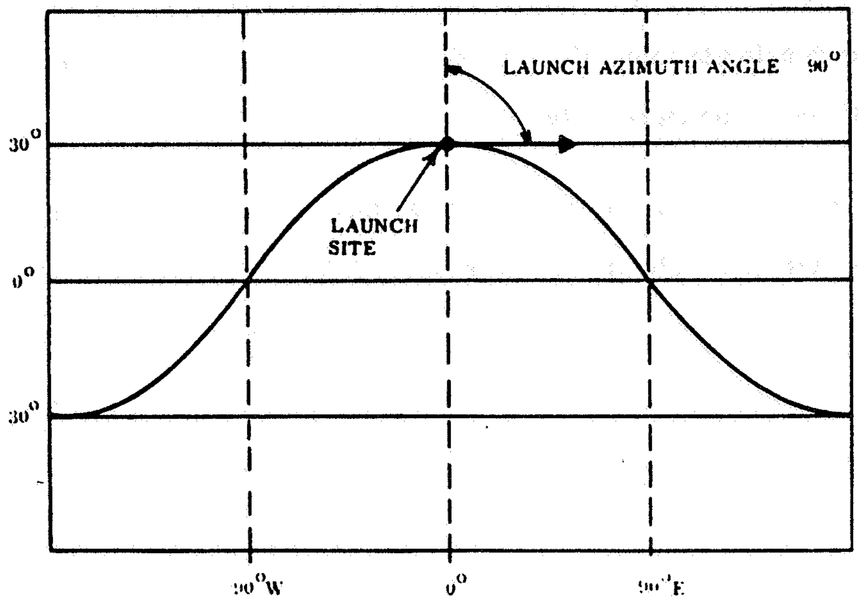


FIGURE 1-8

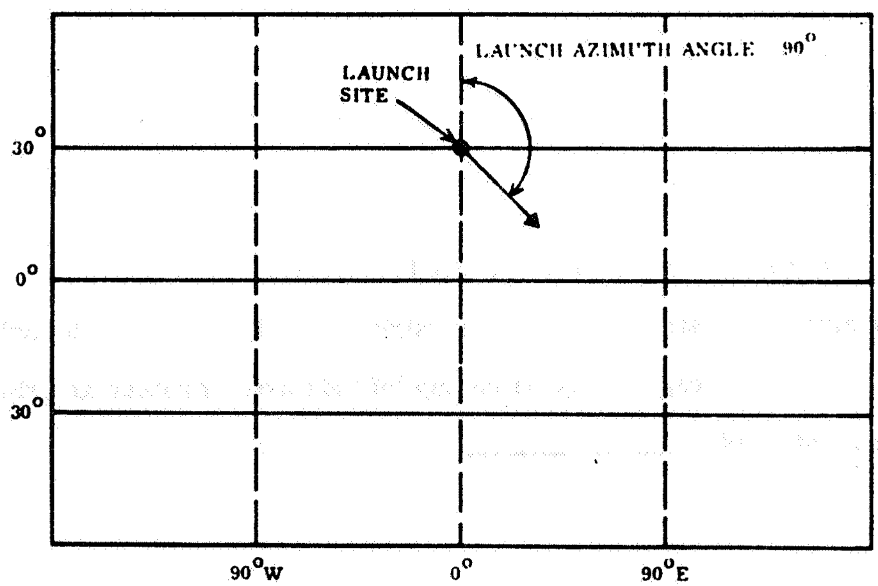


FIGURE 1-9

1-15

<u>ANS-13:</u> 90°

An orbit inclined 90° is a polar orbit and is as inclined as it can get.

Thus, varying the launch azimuth angle from 90° (straight east) to either 0° (straight north) or 180° (straight south) will vary the inclination of the resulting orbit from a value equal to the launch site latitude to 90°. (The actual mathematical relationship is $\cos i = [\cos \lambda] [\sin A]$, where λ is the latitude of the launch site, i is the orbital inclination, and A is the launch azimuth angle. For our purposes, however, knowing the maximums and minimums and the general relationships among the three is sufficient.)

1-16

The launch azimuth angle also determines the location of the orbit's nodes.

14. As you can see in figure 1-8, a 90° launch azimuth angle from a site in the northern hemisphere puts the orbit's descending node ________________ (90° west/90° east) of the launch site. (Don't forget, we are ignoring Earth's rotation.)

1-17

<u>ANS-14:</u> 90° east

The ascending node, of course, would be 90° west of the launch site.

15. Making the launch azimuth angle greater than 90° (figure 1-9) would place the ascending node ________________ (nearer to/further from) the launch site.

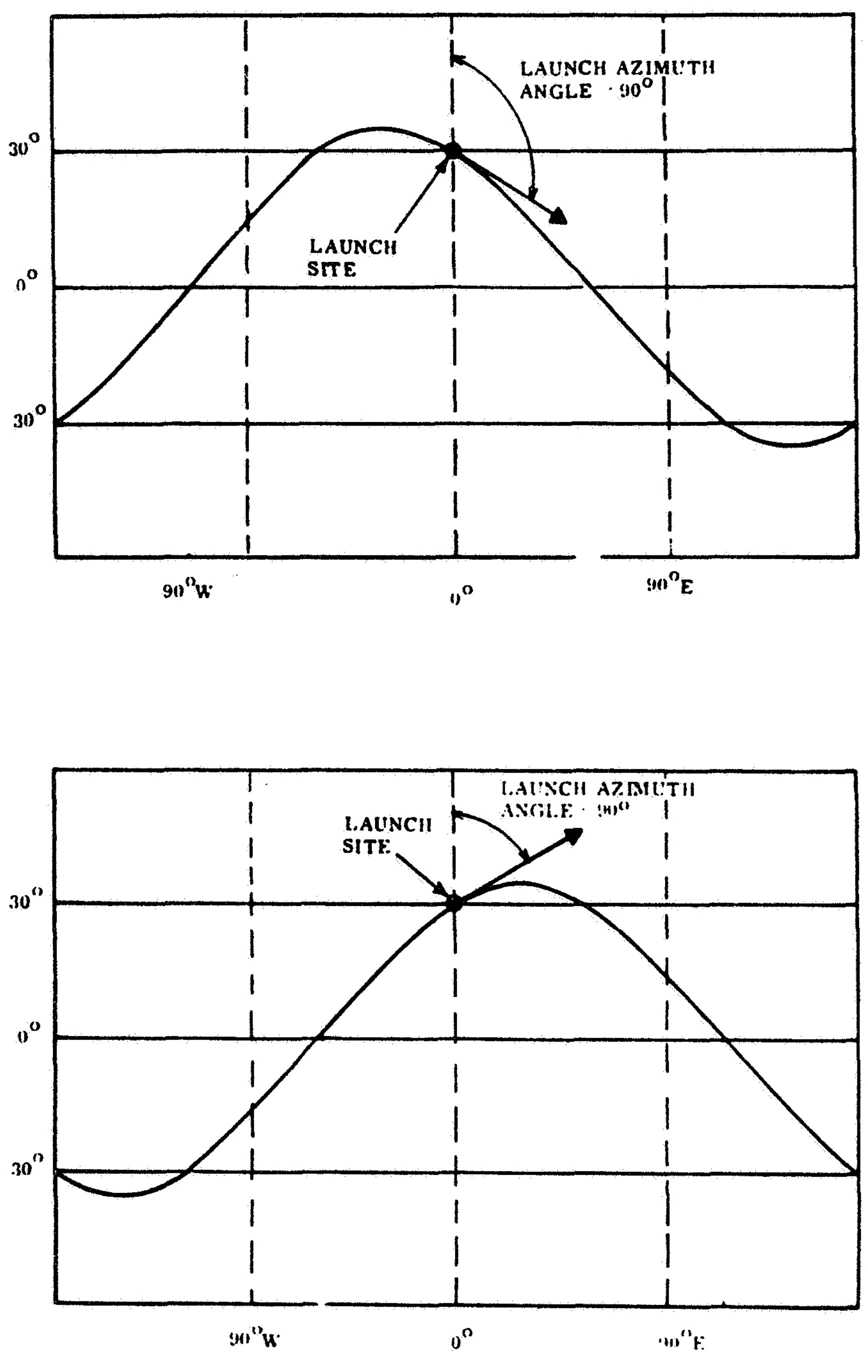

LAUNCH AZIMUTH
ANGLE 90°
LAUNCH
SITE
30°
0°
30°
90°W
0°
90°E
LAUNCH AZIMUTH
ANGLE 90°
LAUNCH
SITE
30°
0°
30°
90°W
0°
90°E

FIGURE 1-10

1-18	

ANS-15: further from

The descending node, of course, would move nearer to the launch site.

Figure 1-10 illustrates what happens to the nodes for launch azimuth angles both larger and smaller than 90^{o}.

16. A launch azimuth angle of 0^{o} would place the ascending node ________________________________ (on the same longitude as the launch site/180^{o} away from the launch site).

1-19	

ANS-16: on the same longitude as the launch site

A launch azimuth angle of 180^{o}, then, would put the ascending node on the opposite side of Earth.

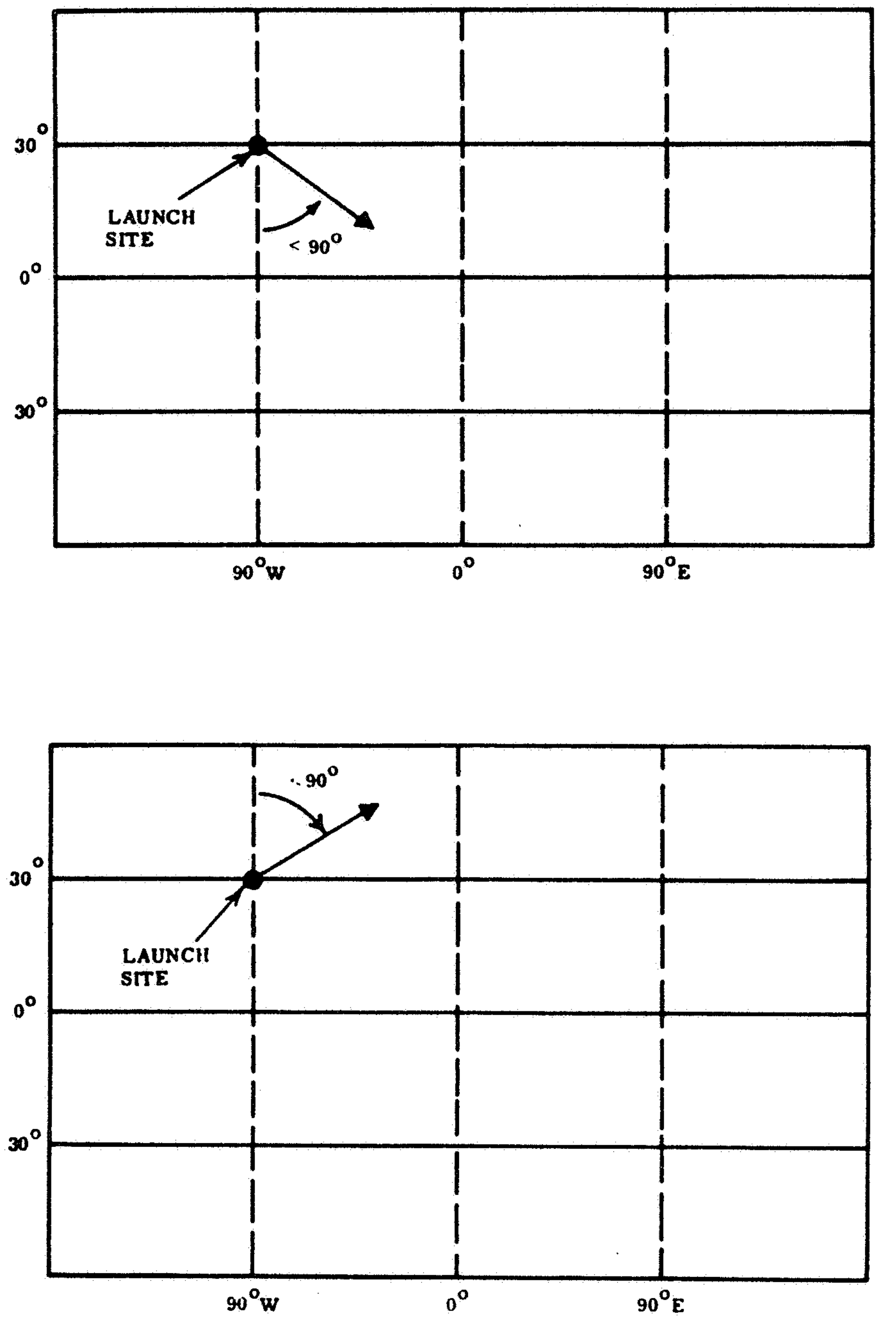


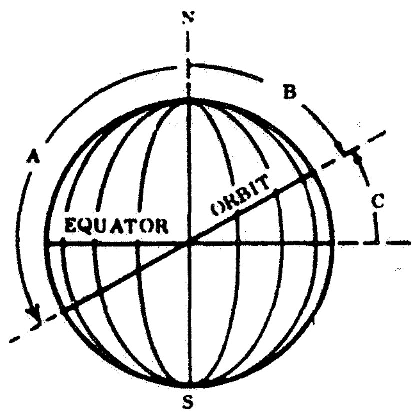
FIGURE 1-11.

17. The maximum orbital inclination which could be achieved from a launch site at 20° north latitude would be ________. The launch azimuth angle required to achieve this inclination would be ________.

18. The minimum orbital inclination which could be achieved from a launch site at 30° north latitude would be ________. The launch azimuth angle required to achieve this inclination would be ________.

19. The descending node of the orbit in question 18 would be ________ (90° west/less than 90° west/90° east/less than 90° east) of the launch site.

20. Sketch the approximate ground tracks that would result from the launch azimuth angles and launch sites shown in figure 1-11.


N
B
A
C
ORBIT
EQUATOR
S

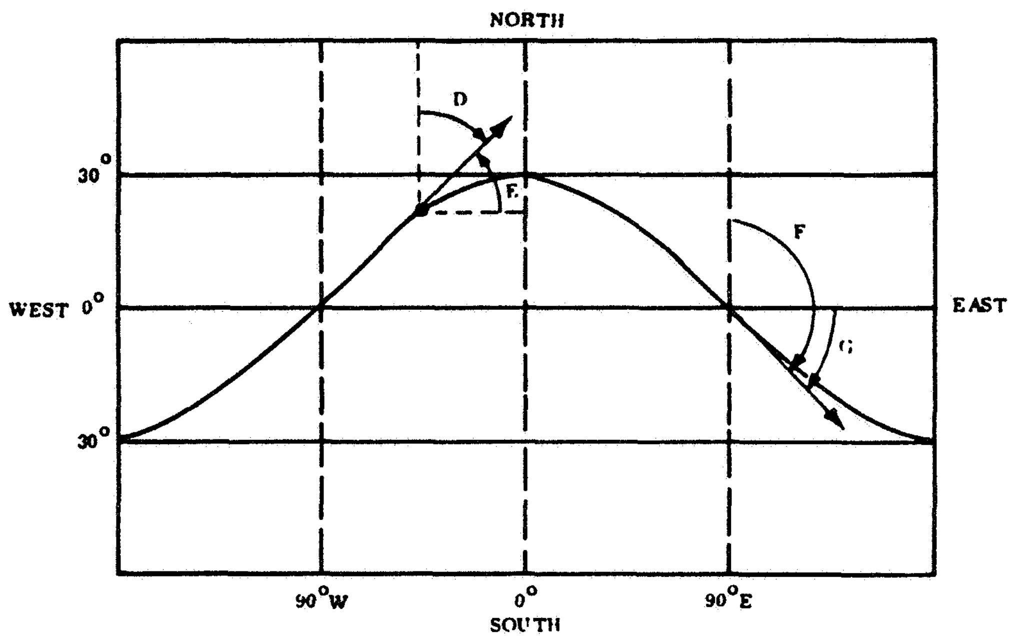

NORTH
D
30°
E
F
WEST 0°
EAST
G
30°
90°W
0°
90°E
SOUTH

FIGURE 1-12.

21. Indicate which of the lettered angles in figure 1-12 correspond to each of the following terms.

__________ Heading angle

__________ Orbital inclination

__________ Launch azimuth angle

22. An orbital inclination of 40° could be achieved from a latitude of 30° south only by making the launch azimuth angle ____________________ .

A. less than 90°

B. greater than 90°

C. $+10^{\circ}$

D. -10°

E. either greater or less than 90°

ANS-17: 90° (frames 1-14, 1-15)

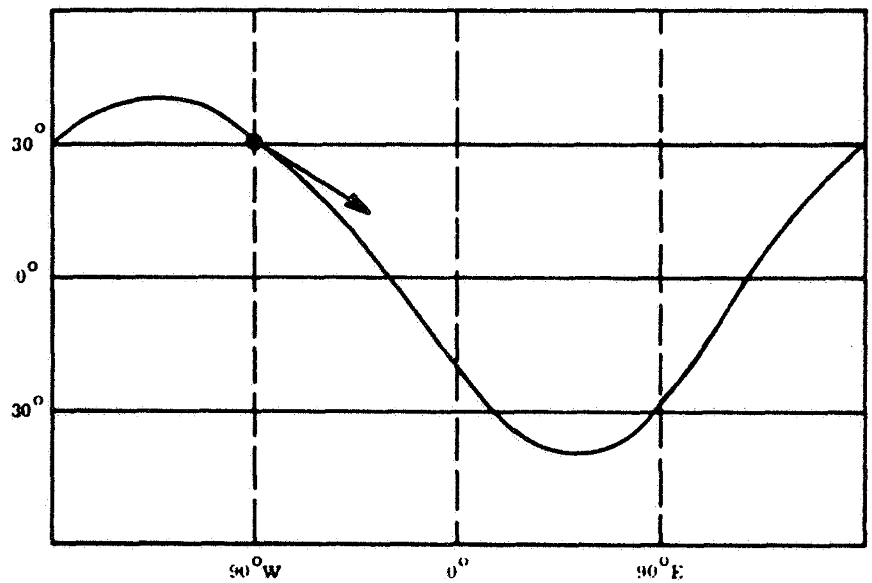
0° or 180°

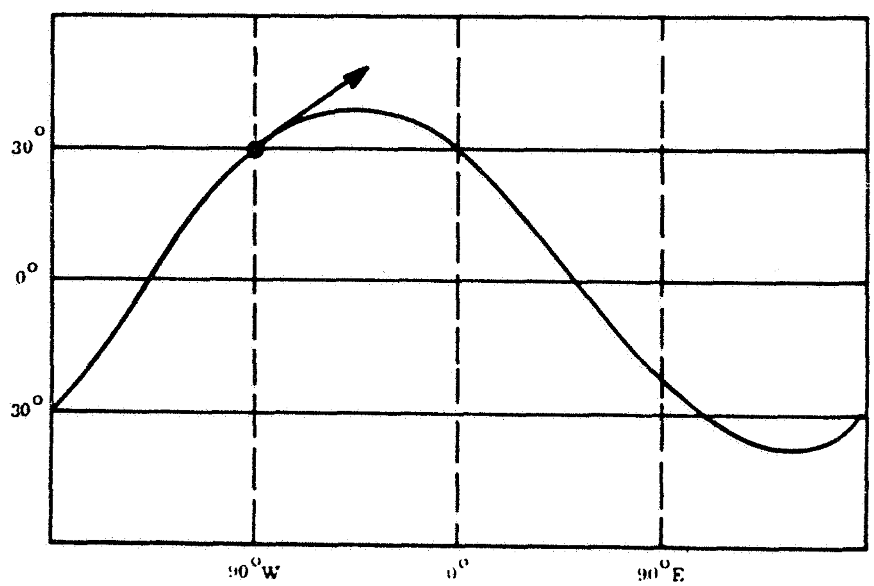
ANS-18: 30° (frames 1-7, 1-8)

90°

ANS-19: 90° east (frame 1-10)

ANS-20:





ANS-21:	F	Heading angle (D could also be thought of as the heading angle, but only at the time of launch. Thus, F would be a better choice.)	(frame 1-9)
	B	Orbital inclination	(figures 1-3, 1-4)
	D	Launch azimuth angle	(figure 1-7)
ANS-22:	E.	either greater or less than 90^{o}	(frames 1-13, 1-14)

SECTION 2

INSERTION INTO ORBIT

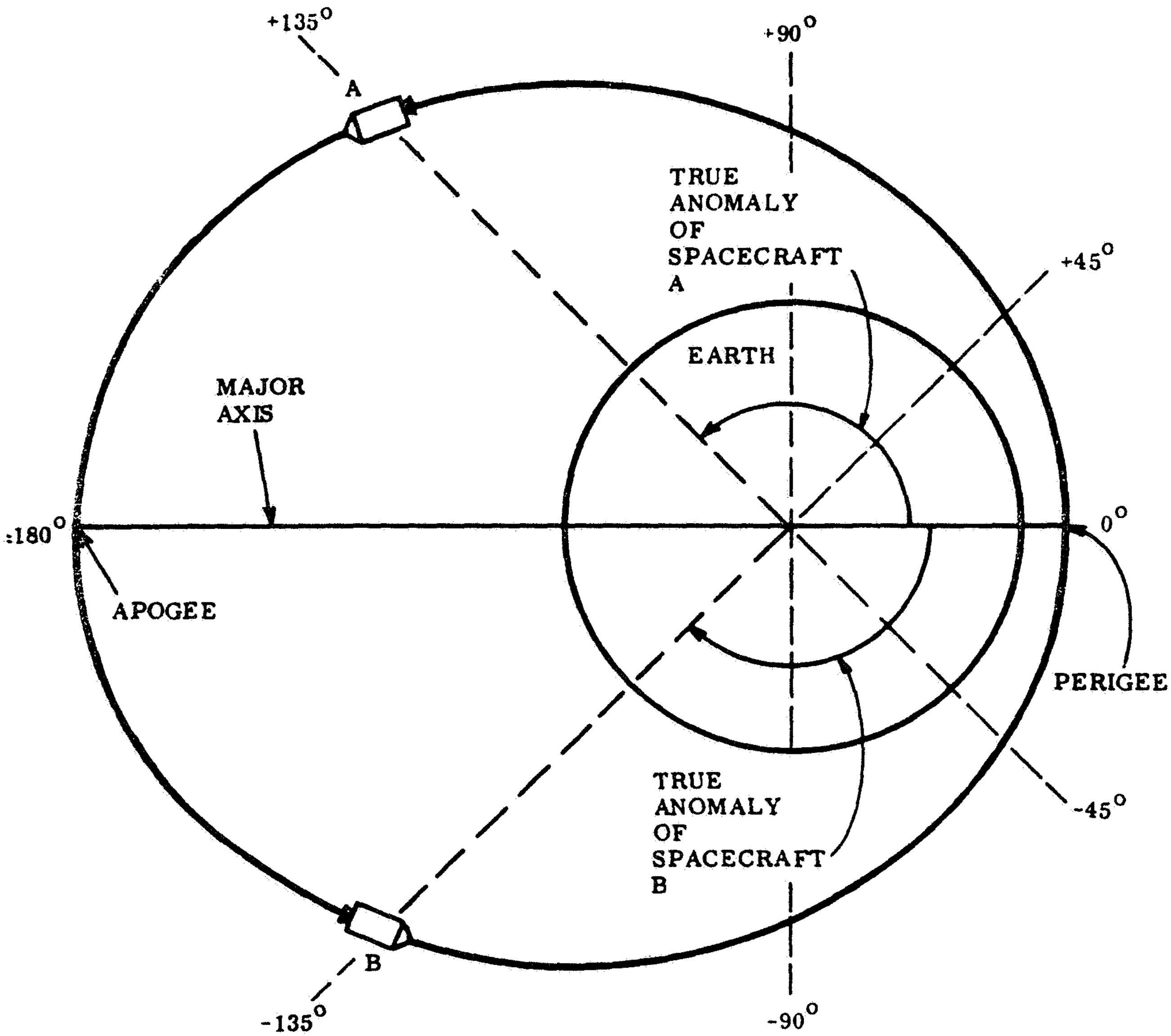

+135°
+90°
A
TRUE
ANOMALY
OF
SPACECRAFT
A
+45°
EARTH
MAJOR
AXIS
±180°
0°
APOGEE
PERIGEE
TRUE
ANOMALY
OF
SPACECRAFT
B
-45°
B
-135°
-90°

FIGURE 2-1

2-1

In section 1, we limited the discussion to orbital characteristics that primarily affected the ground track. In this section we will take up a different set of characteristics, including perigee and apogee, which primarily affect the "space track" but have little effect on the ground track.

First there is true anomaly, shown in figure 2-1.

1. From figure 2-1, you can see that the true anomaly is the angle between the spacecraft's present position and ______________ (perigee/apogee).

2-2

ANS-1: perigee

Notice that true anomaly is similar to longitude in that it goes to 180° in each direction rather than from 0° to 360° in one direction.

2. As you can see, the true anomaly of a spacecraft traveling away from perigee, toward apogee, is always ______________ (positive/negative), while that of a spacecraft that has passed apogee and is returning toward perigee is always ______________ (positive/negative).

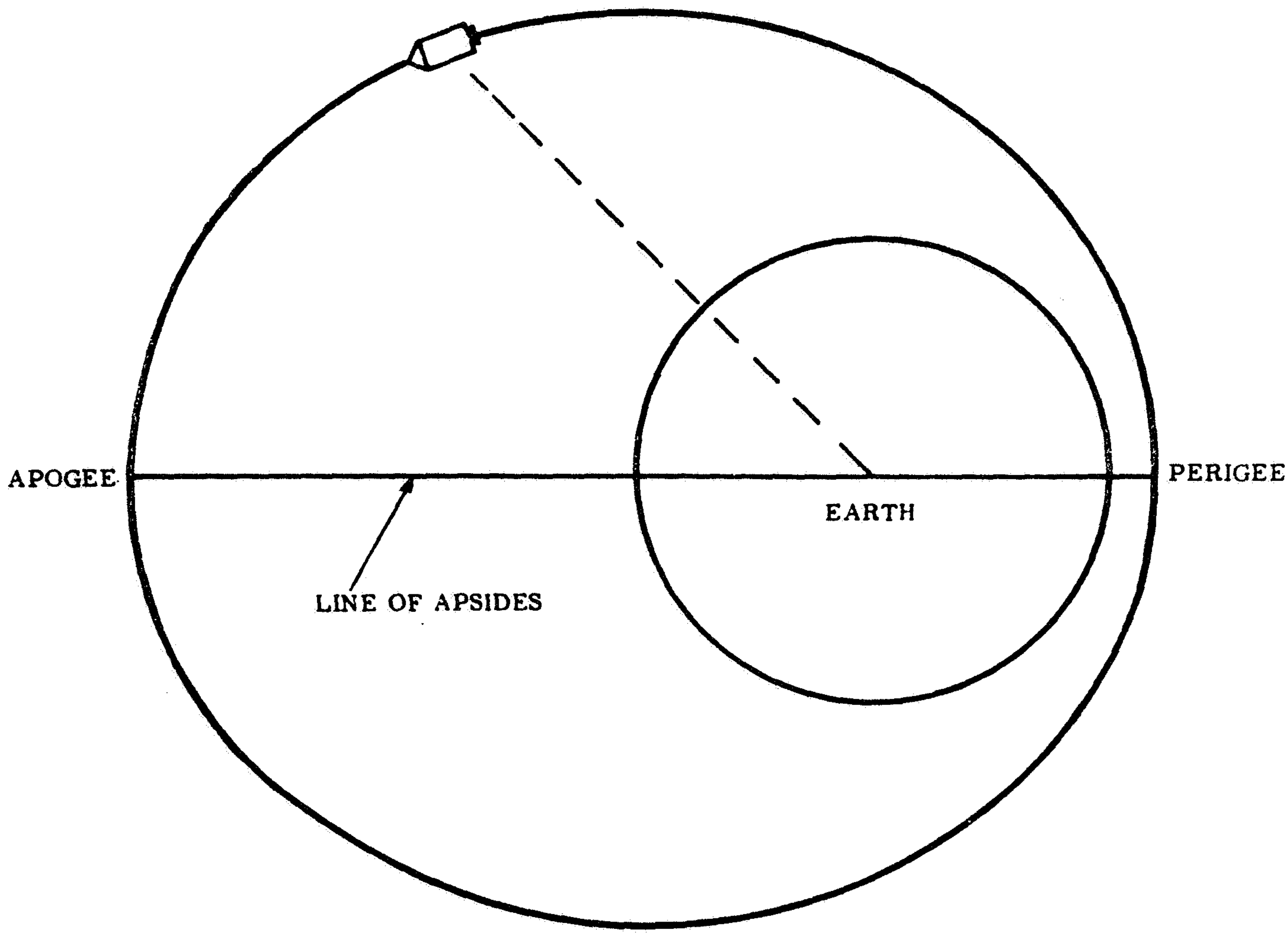


FIGURE 2-2

ANS-2: positive

negative

At apogee, then, the true anomaly would be $\pm 180^{o}$.

Remember that perigee and apogee are always directly opposite each other in any elliptical orbit. The line connecting perigee and apogee coincides with the orbit's major axis and is called the line of apsides, pronounced ăp′ sĭ dēs.

3. As you can see in figure 2-2, the line of apsides also passes through the

______________________________.

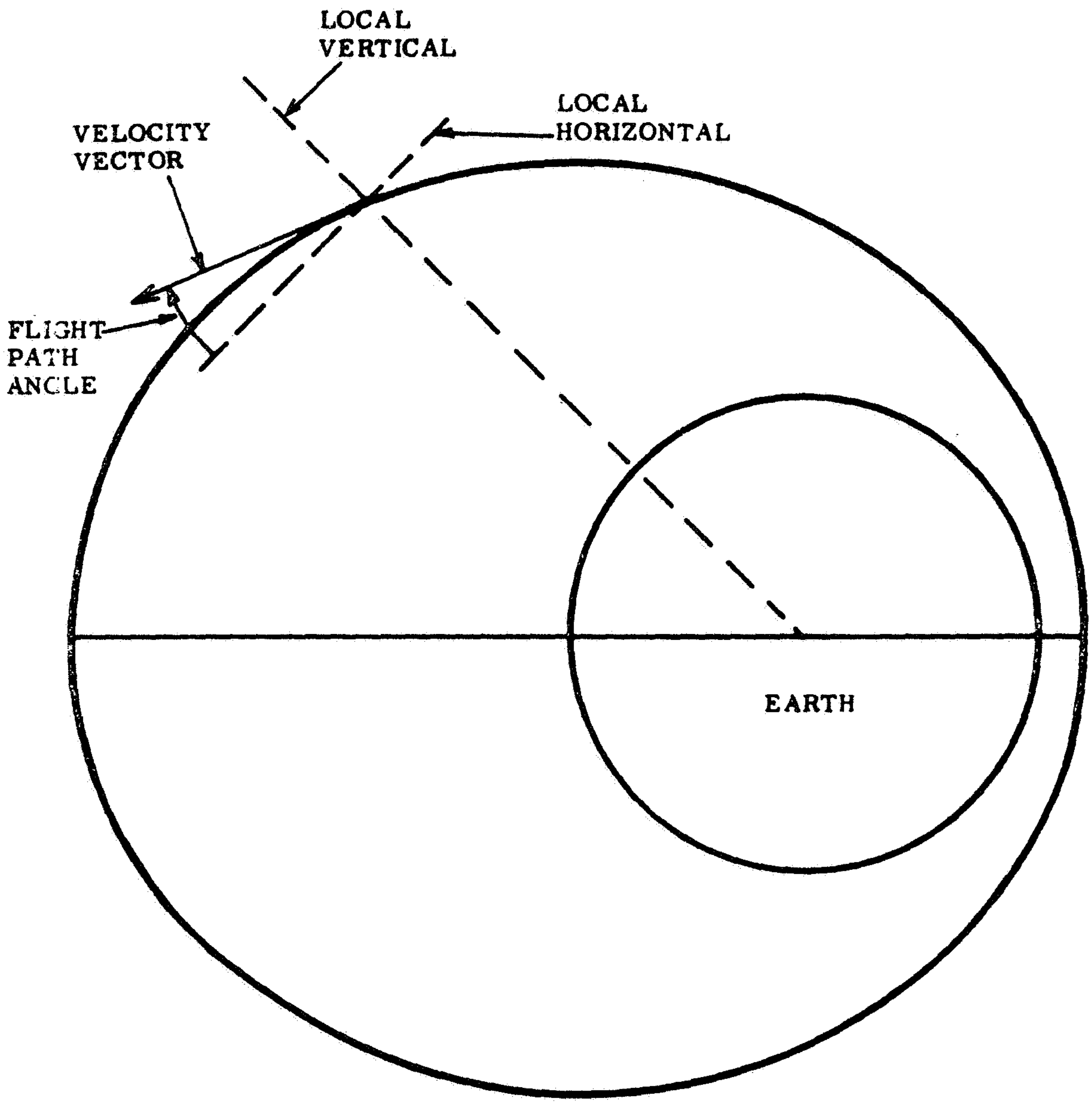

LOCAL
VERTICAL
LOCAL
HORIZONTAL
VELOCITY
VECTOR
FLIGHT
PATH
ANGLE
EARTH

FIGURE 2-3

2-4	

ANS-3: center of the Earth

Or the center of whatever body the spacecraft is in orbit about.

Another characteristic--one which varies with true anomaly--is flight path angle, shown in figure 2-3.

4. From figure 2-3, you can see that the flight path angle is the angle between the actual direction of spacecraft travel (i.e., tangent to the spacecraft orbit) and local ____________ (vertical/horizontal).

2-5	

ANS-4: horizontal

As shown in figure 2-3, local horizontal is simply a line perpendicular to local vertical.

5. As a spacecraft leaves the launch pad, traveling straight up, its flight path angle would be ________________ degrees.

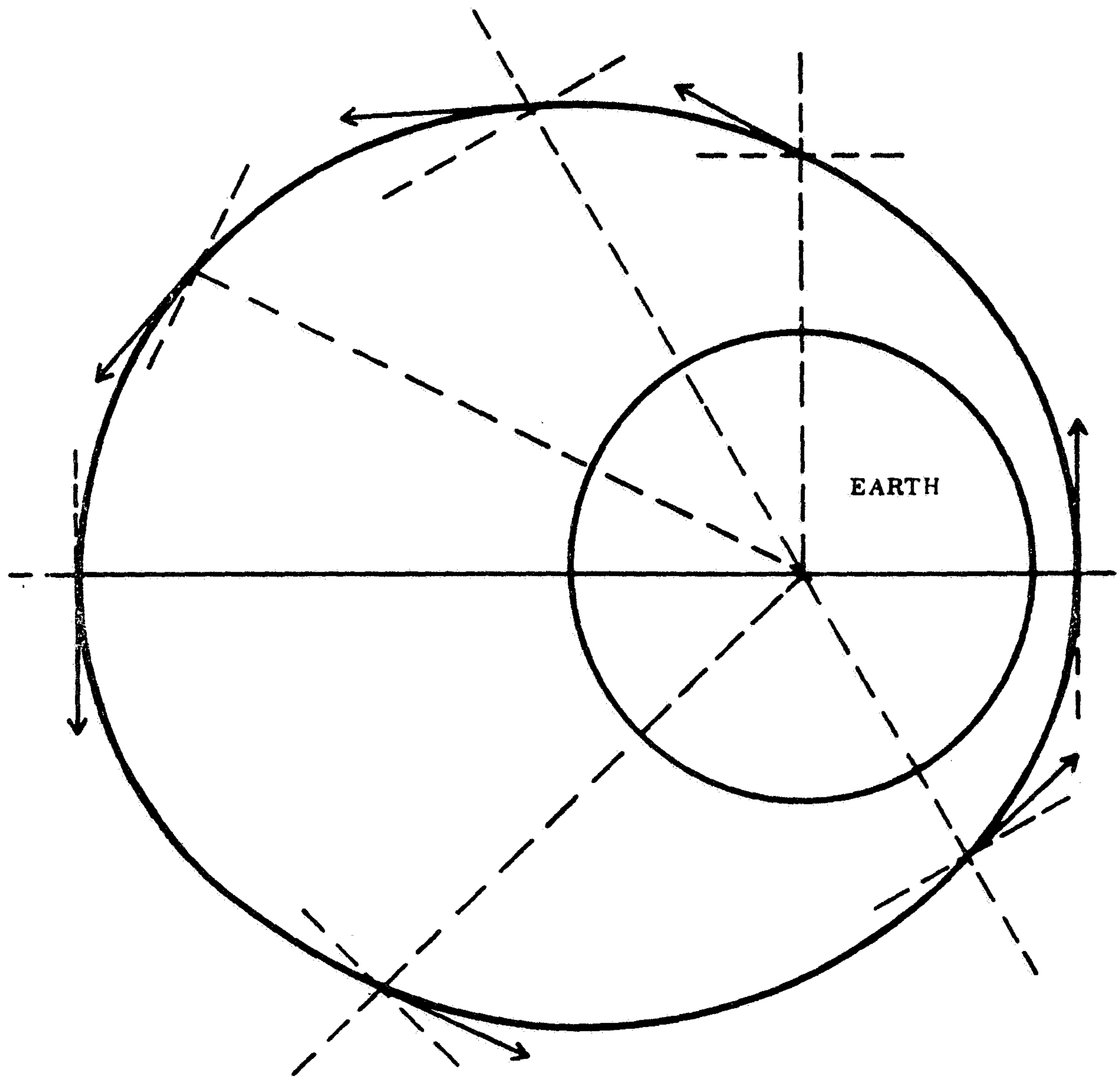


FIGURE 2-4

ANS-5: 90

We will assume it to be $+90^{\circ}$, which means that if you drop a rock down an elevator shaft, the rock would have a flight path angle of -90°. (Don't forget, we are not taking Earth's rotation into account. If we were, we would speak of the inertial flight path angle and would say that a body at rest on the surface of the Earth would have an inertial flight path angle of 0°. Thus, the inertial flight path angle of a spacecraft going "straight up" at about 1,000 mph would be about 45°. In this text, however, we will speak only of flight path angle and will not take Earth's rotation into account.)

Figure 2-4 shows how the flight path angle varies with true anomaly.

6. From perigee to apogee, the spacecraft is moving generally ________________ (toward/away from) Earth and has a ____________ (positive/negative) flight path angle.

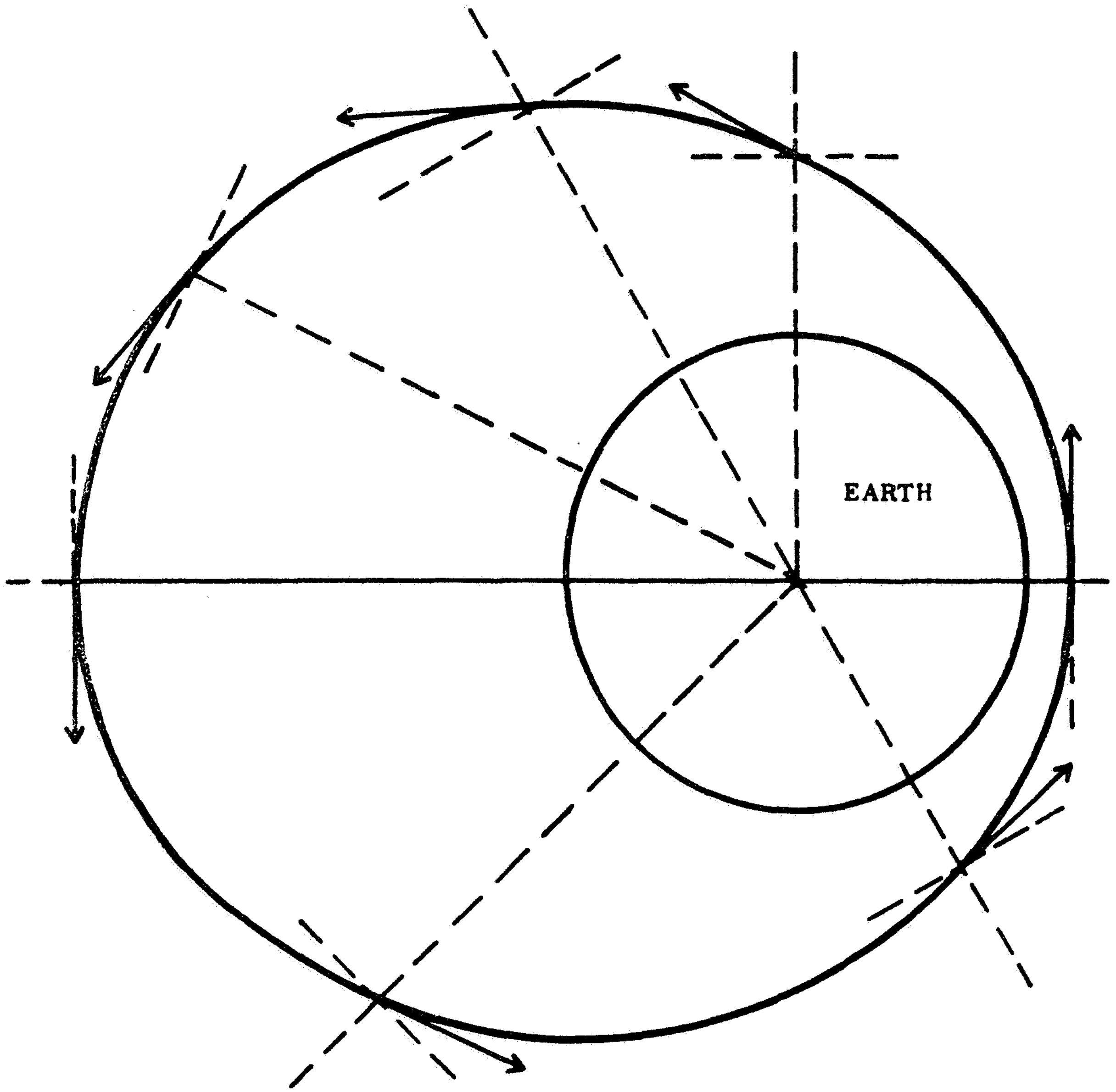


FIGURE 2-4

2-7

ANS-6: away from

positive

As the spacecraft moves back toward perigee, it is traveling toward Earth and has a negative flight path angle.

7. At perigee and apogee, however, the spacecraft is neither traveling toward nor away from Earth, so its flight path angle (figure 2-4) is __________ degrees.

2-8

ANS-7: 0

Thus, by knowing the flight path angle, you can tell which half of the orbit the spacecraft is in.

8. A positive flight path angle means the spacecraft has a ______________ (positive/negative) true anomaly and is approaching ______________ (perigee/apogee).

9. A flight path angle of 0^{o} means the spacecraft is at ____________________.

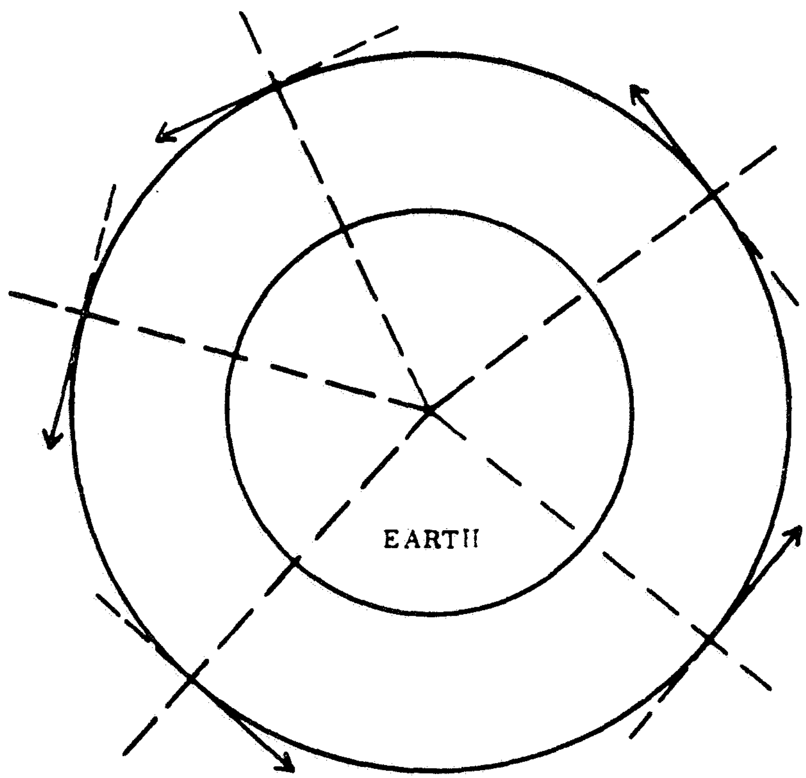


FIGURE 2-5

ANS-8: positive

apogee

ANS-9: at either apogee or perigee

Actually, a flight path angle of 0° could also mean that the spacecraft was in a circular orbit (figure 2-5), which would have no perigee or apogee but would have a constant flight path angle of 0°.

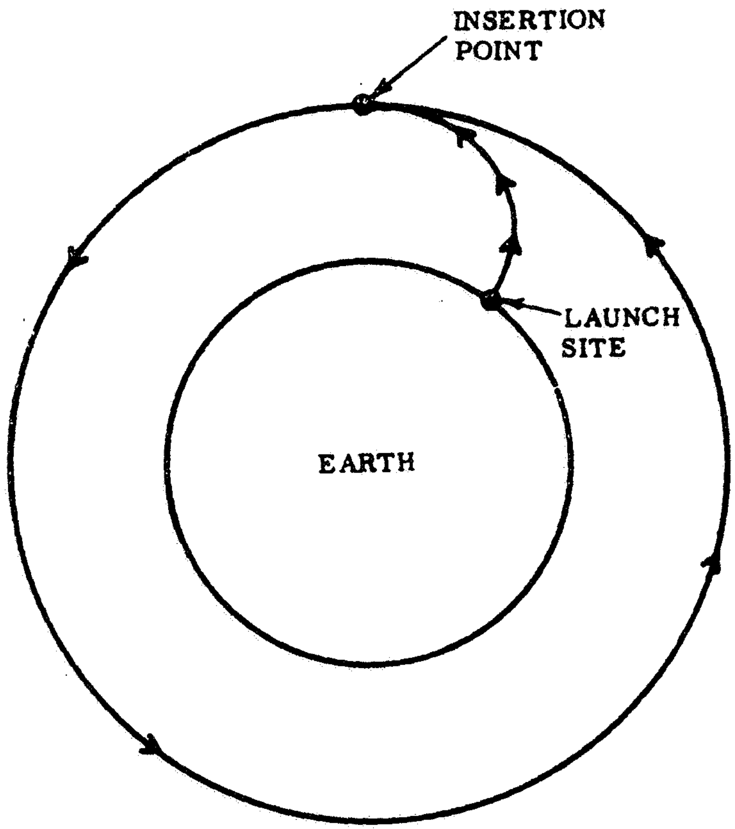


FIGURE 2-6

2-10

In section 1, we spoke only of "launching" a spacecraft into orbit, and we acted as if the spacecraft achieved its orbit directly over the launch site. As far as orbital inclination and launch azimuth angle are concerned, this simplified view is sufficient. In talking about apogee, perigee, and flight path angle, however, we have to be more specific and introduce a new term, insertion point. The insertion point, illustrated in figure 2-6, can be defined as the point at which the spacecraft actually enters its orbit.

10. The insertion point would occur ____________________ (before/after/at the same time as) engine cutoff.

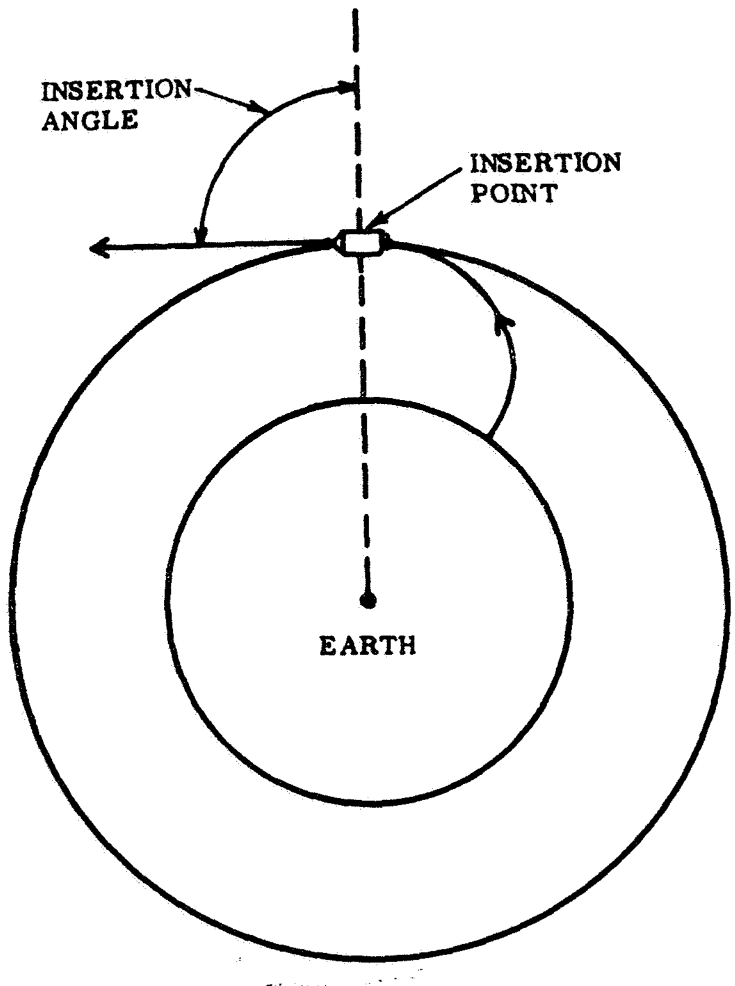


FIGURE 2-7

2-11	

ANS-10: at the same time as

The point at which engine cutoff occurs becomes, by definition, the insertion point. Prior to cutoff, the spacecraft has been in powered flight, not in orbit.

The shape of the orbit is determined by the speed and direction of the spacecraft at the insertion point.

11. The insertion angle (figure 2-7) defines the direction of the spacecraft at the insertion point and is measured between the line of spacecraft motion and ______________________ (local horizontal/local vertical).

2-12	

ANS-11: local vertical

An insertion angle of 90°, then, would mean that the spacecraft was traveling along local horizontal.

12. An insertion angle of 90° would produce an initial flight path angle of ____________ degrees.

2-13	

ANS-12: 0

Similarly, an insertion angle of 0° would produce a flight path angle of +90°, not to mention a pretty bad orbit.

13. Unless the resulting orbit is a perfect circle, an insertion angle of 90° would produce an orbit in which the insertion point coincided with ________________ (apogee/perigee/either apogee or perigee/neither apogee nor perigee).

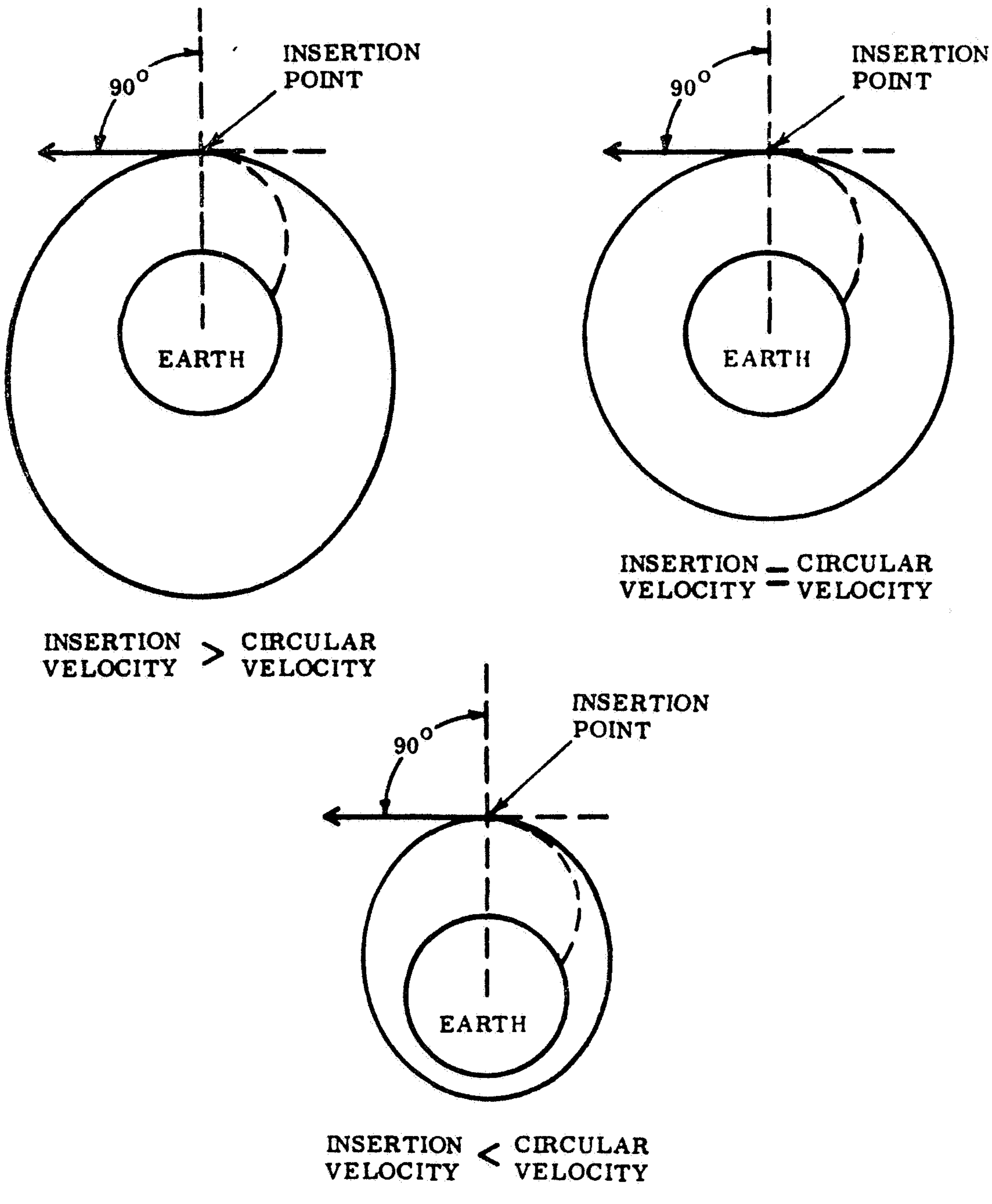

90°
INSERTION POINT
EARTH
INSERTION VELOCITY > CIRCULAR VELOCITY
90°
INSERTION POINT
EARTH
INSERTION VELOCITY = CIRCULAR VELOCITY
90°
INSERTION POINT
EARTH
INSERTION VELOCITY < CIRCULAR VELOCITY

FIGURE 2-8

2-14

ANS-13: either apogee or perigee

Whether the insertion point coincides with perigee or apogee depends on whether the insertion velocity is greater or less than circular velocity. (Circular velocity is simply the velocity necessary to produce a circular orbit.) Orbits resulting from these different insertion velocities (with the insertion angle held at 90^{o}) are shown in figure 2-8.

14. A velocity greater than circular velocity would produce an orbit in which the insertion point would coincide with __________ .

2-15

ANS-14: perigee

Apogee, of course, would be 180^{o} away from the insertion point. A velocity less than circular velocity, on the other hand, would place the resulting orbit's apogee at the insertion point and perigee 180^{o} away.

Another way of looking at it is this: The height of the spacecraft on the opposite side of the orbit (whether it is apogee or perigee) depends on the insertion velocity.

15. Assuming an insertion angle of 90^{o}, which of the following insertion velocities would result in the greatest altitude for the spacecraft when it is 180^{o} away from the insertion point? __________

A. 19,000 mph

B. 20,000 mph

C. 21,000 mph

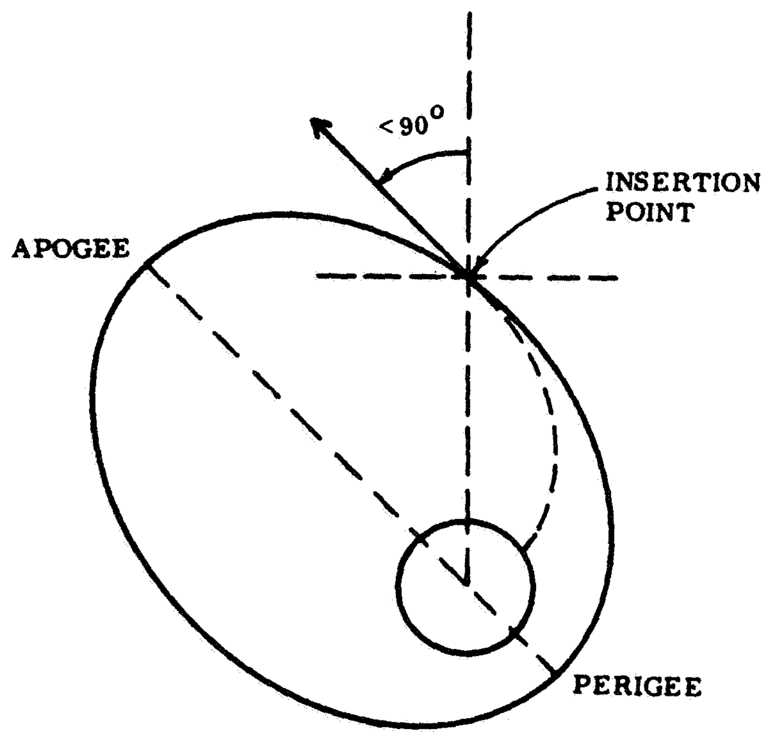


FIGURE 2-9

2-16	·

ANS-15: C. 21,000 mph

The greater the insertion velocity, the higher the orbit on the opposite side.

Now let's hold the insertion velocity equal to circular velocity and vary the insertion angle.

16. TRUE or FALSE? With an insertion angle other than 90°, an orbit in which the insertion point coincided with perigee could not be produced. ________________

2-17	

ANS-16: TRUE

Remember, the flight path angle at apogee and perigee is always 0°, and the only way to get a flight path angle of 0° at the insertion point is to have an insertion angle of 90°.

17. As a result of an insertion angle less than 90°, shown in figure 2-9, the spacecraft would have a ______________(positive/negative) initial flight path angle and would be moving toward ____________________(perigee/apogee).

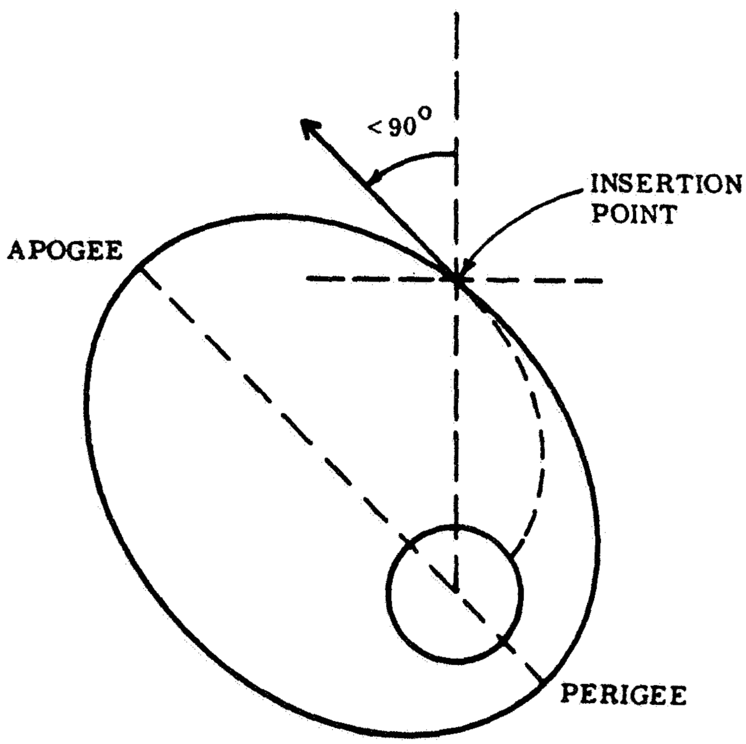


FIGURE 2-9

2-18	

ANS-17: positive

apogee

The example in figure 2-9 is, of course, exaggerated. Insertion angles would normally be held very close to 90°. We can use this illustration, however, to point out an interesting result of varying the insertion angle.

First, notice the orientation of the line of apsides.

18. The line of apsides appears to be ____________ (perpendicular/parallel) to the insertion velocity vector.

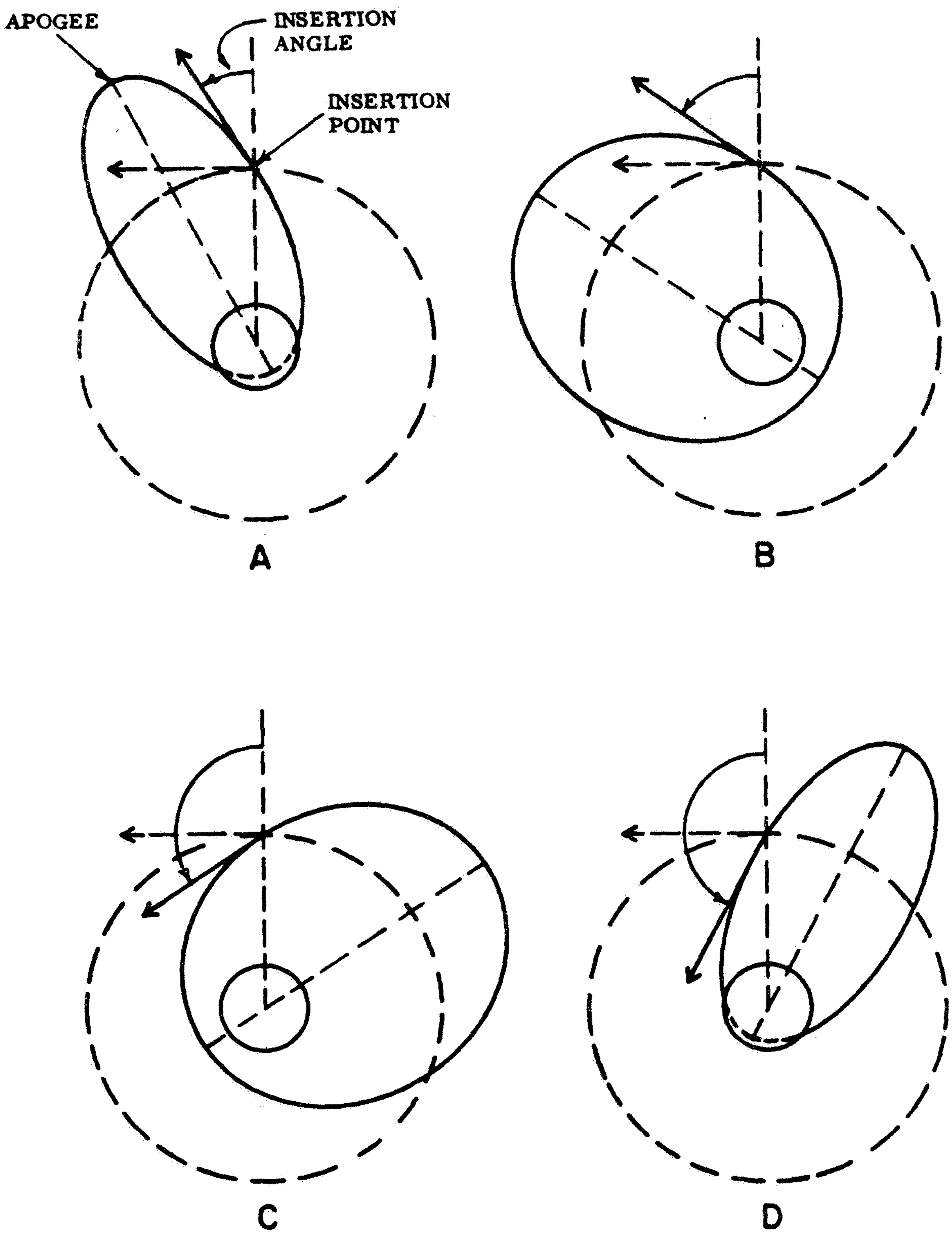


FIGURE 2-10

2-19

ANS-18: parallel

Interestingly enough, this relationship holds for all insertion angles as long as the insertion velocity is held equal to circular velocity for the insertion point. The sequence in figure 2-10 shows what happens to an orbit as the insertion angle is varied. (Don't worry about the fact that a couple of the orbits intersect the surface of the Earth. It's the principle of the thing we're illustrating, not orbits that would actually be used.)

19. Notice that, as the insertion angle crosses 90°, apogee and perigee reverse. That is, for an insertion angle of 89°, apogee would be reached 89°__________ (after/before) the insertion point, but for an insertion angle of 91°, apogee would be reached 89°__________ (after/before) the insertion point.

2-20

ANS-19: after

before

20. This reversal is logical enough if you remember that a positive flight path angle (resulting from an insertion angle of less than 90°) means that the spacecraft is moving toward __________ (apogee/perigee), and that a negative flight path angle (resulting from an insertion angle of more than 90°) means that the spacecraft is moving toward __________ (apogee/perigee).

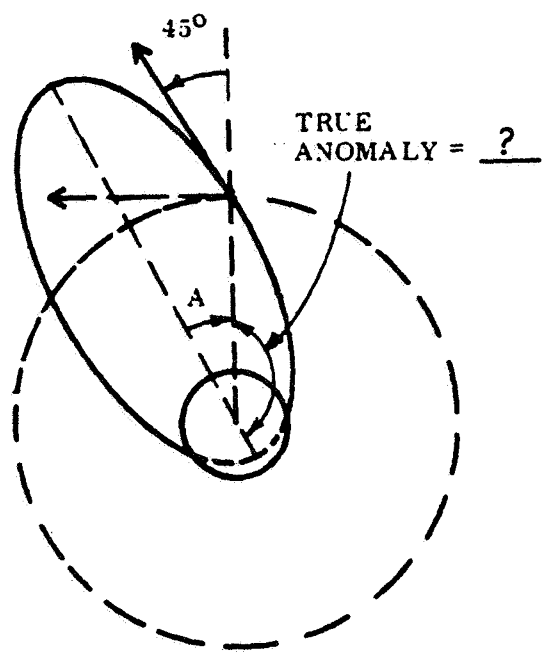


FIGURE 2-11

2-21	

ANS-20: apogee

perigee

Another way of looking at the orbits is to define the true anomaly of the insertion point. Let's start with an insertion angle of 45°, as shown in figure 2-11. Remember that the insertion velocity vector and the line of apsides are parallel. Then, from basic geometry, you can see that the insertion angle is equal to angle "A".

21. This means that, in our example, the insertion point is 45° away from ______________ (apogee/perigee).

2-22	

ANS-21: apogee

True anomaly, however, is a measure of how far the spacecraft (or the insertion point, in this case) is from perigee.

22. To find true anomaly, then, you simply subtract angle "A" (45°) from ________ .

2-23	

ANS-22: 180°

Thus, the true anomaly of the insertion point in figure 2-11 is $+135^{\circ}$.

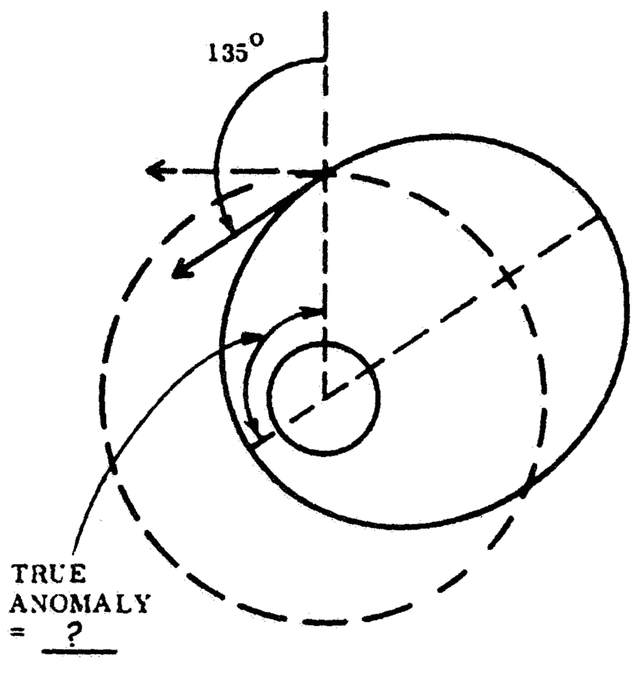


FIGURE 2-12

2-24

Now let's look at an insertion angle of 135°, shown in figure 2-12.

23. Notice that, in this case, the true anomaly is equal to ____________

(the insertion angle/180° minus the insertion angle).

2-25

ANS-23: the insertion angle

24. Since the spacecraft is moving toward perigee, however, the true anomaly is ____________ (positive/negative).

2-26

ANS-24: negative

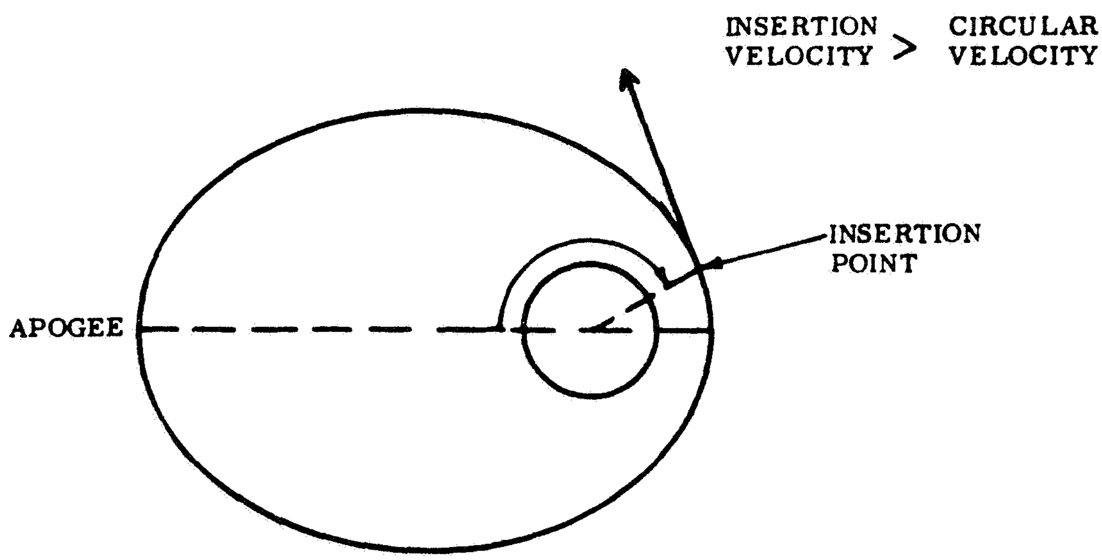
Thus, the true anomaly would be -135°.

25. TRUE or FALSE? Assuming an insertion velocity equal to circular velocity, the true anomaly of an insertion point could never be between $+90^{\circ}$ and -90°. ____________

2-27

ANS-25: TRUE

If you have any doubts about this, just remember that, as the insertion angle passes through 90°, apogee and perigee reverse, which means that the true anomaly of the insertion point jumps from $+90^{\circ}$ to -90°.



INSERTION VELOCITY > CIRCULAR VELOCITY
INSERTION POINT
APOGEE

FIGURE 2-13

2-28

For insertion velocities other than circular velocity, all we can do (without getting beyond the scope of this text, that is) is make a couple of generalizations.

26. For example, even without knowing the insertion velocity, you know that an insertion angle less than 90° gives you a ______________ (negative/positive) initial flight path angle, which means that the spacecraft is heading toward ____________ (apogee/perigee).

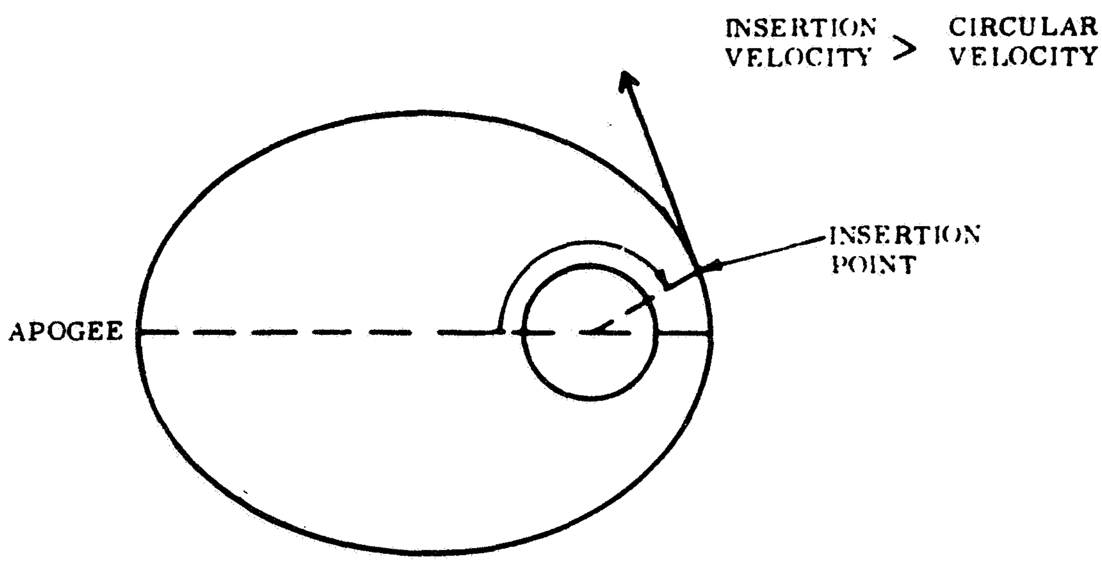
2-29

ANS-26: positive

apogee

But, how far does it have to go before it reaches apogee? This is dependent not only on the insertion angle but on the insertion velocity. It is not necessarily within the next 90°, as it was when insertion velocity equalled circular velocity. In figure 2-13 for instance, where the insertion velocity is considerably greater than circular velocity, apogee is well over 90° away from the insertion point.

27. All we can say for sure is that, for insertion angles less than 90°, apogee must occur somewhere within the first ______________ degrees.



INSERTION VELOCITY > CIRCULAR VELOCITY
INSERTION POINT
APOGEE

FIGURE 2-13

<u>ANS-27:</u> 180

The farthest you can be from apogee and have a positive flight path angle is a point just past perigee, 180° away. Thus, when you have a positive initial flight path angle, you have to reach apogee within 180°.

28. Similarly, an insertion angle greater than 90° gives you a ____________ (positive/negative) initial flight path angle, which means that the spacecraft will reach ____________ (apogee/perigee) within the first __________ degrees.

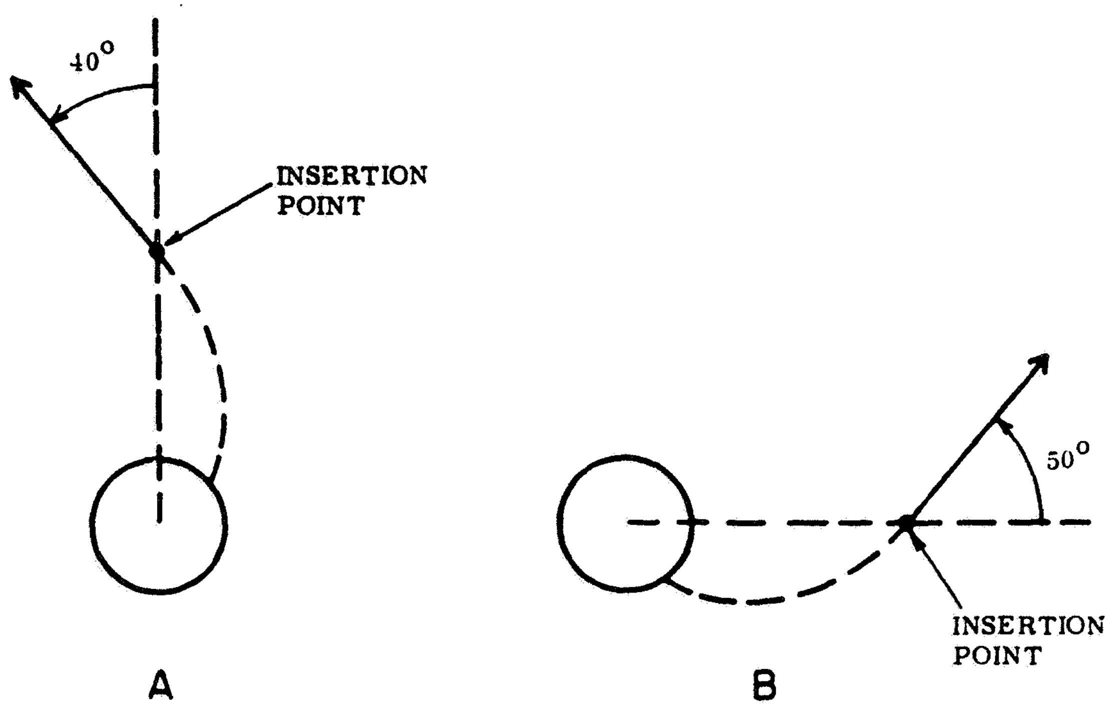


FIGURE 2-14

ANS-28: negative

perigee

180

Assume the insertion velocity is equal to circular velocity for each insertion point in figure 2-14.

29. Sketch the approximate orbits that would result from the two insertions shown in figure 2-14. Indicate the line of apsides, perigee, and apogee in each.

30. The true anomaly of the insertion points in figure 2-14 are:

A. ____________________

B. ____________________

31. What would be the true anomaly of a spacecraft 10^{o} past apogee? __________

30^{o} before it reaches apogee? ______________

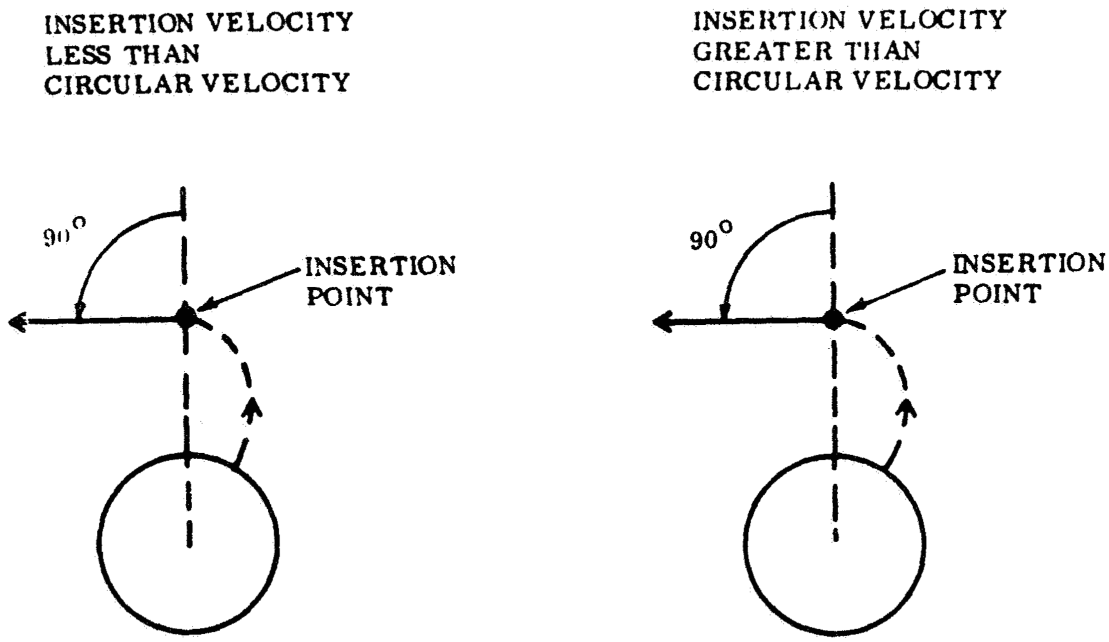


FIGURE 2-15

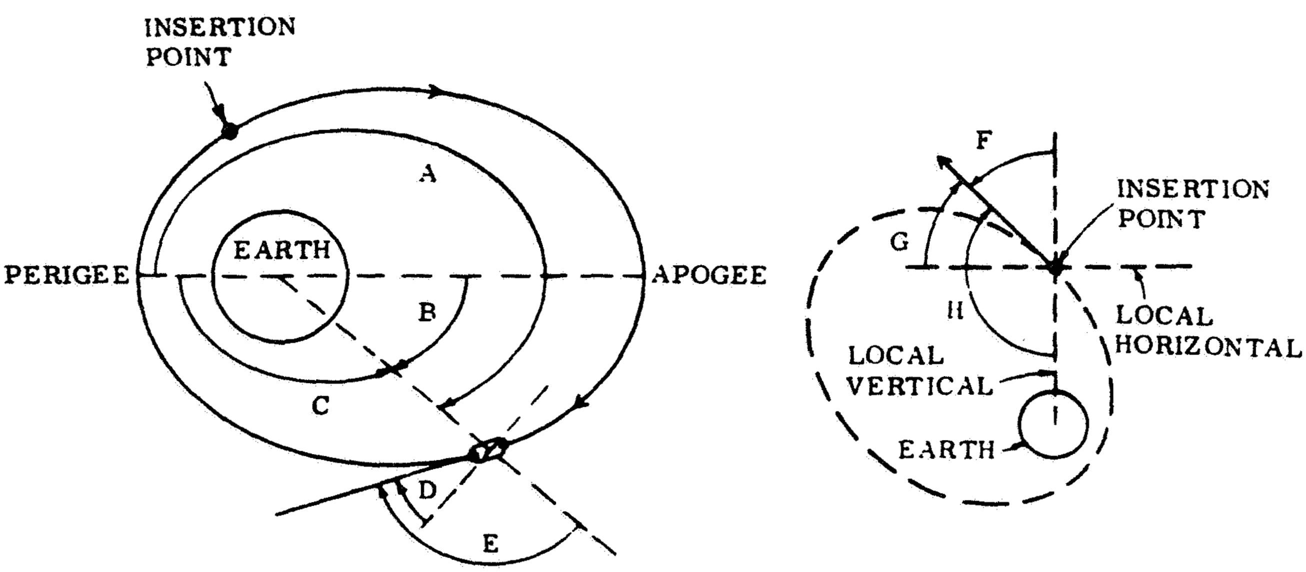


FIGURE 2-16

32. Sketch the approximate orbits that would result from the insertion shown in figure 2-15. Indicate the line of apsides, apogee, and perigee in each.

33. Indicate which of the lettered angles in figure 2-16 correspond to each of the following.

________ Insertion angle

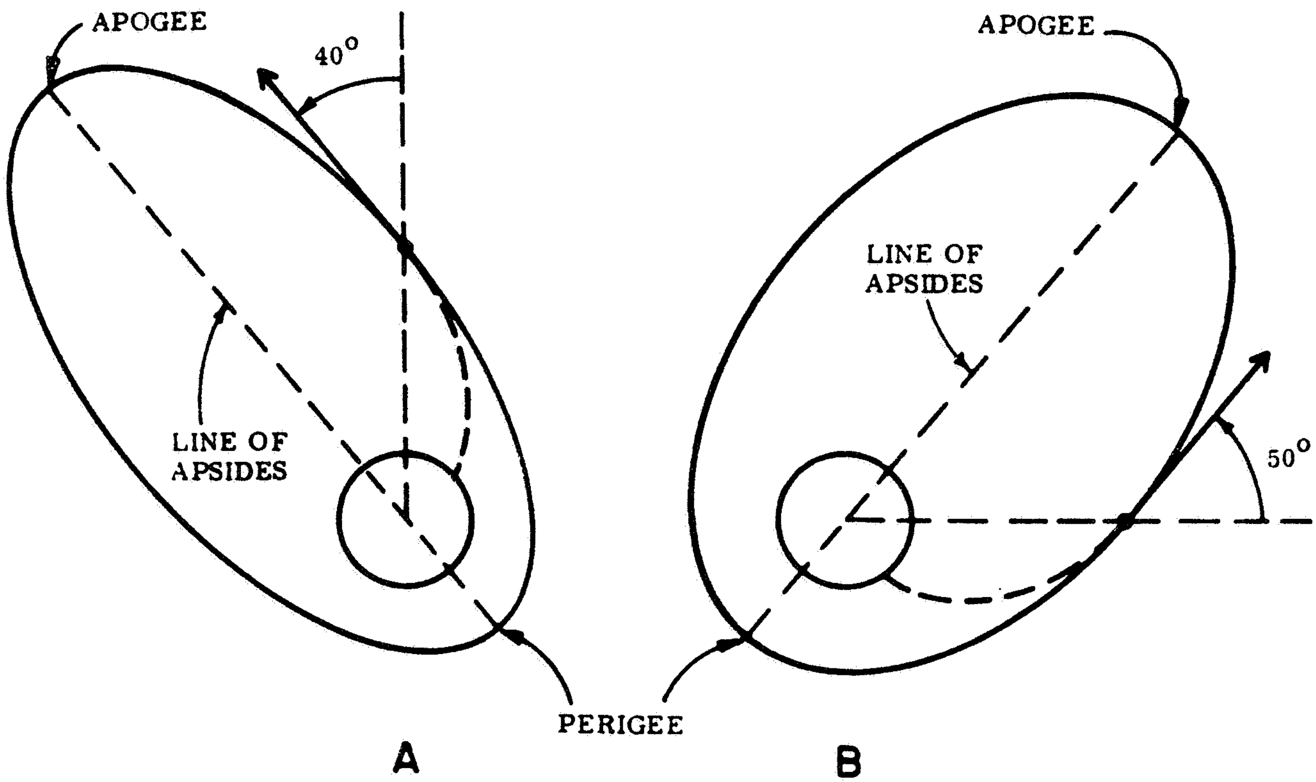
________ Flight path angle

________ True anomaly

34. If the flight path angle of a spacecraft is always 0°, the orbit is

____________________________.

ANS-29: (frames 2-16 thru 2-20)



2-32	ANSWERS TO REVIEW QUESTIONS (continued)

ANS-30: A. 140° (frames 2-21 thru 2-27)

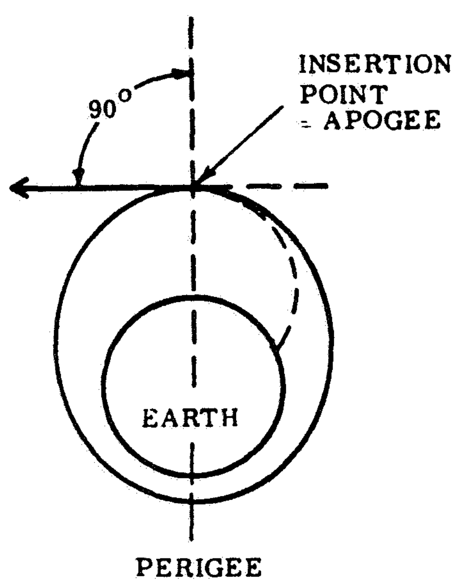
B. 130°

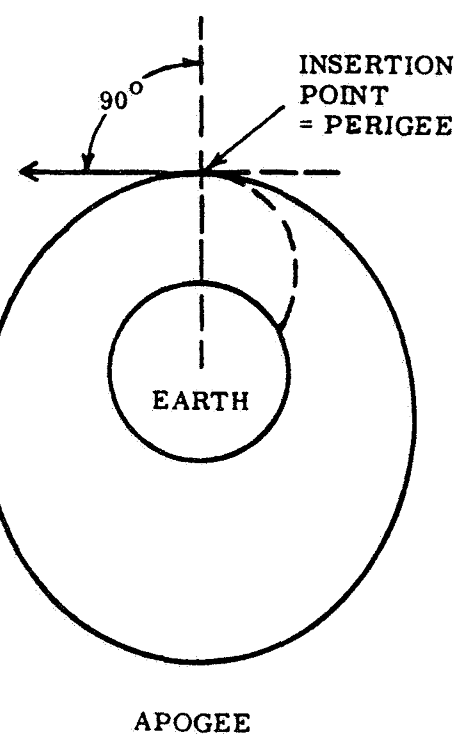
ANS-31: -170° (frames 2-1, 2-2, 2-3)

•150°

ANS-32: (frames 2-14, 2-15)

INSERTION VELOCITY LESS THAN CIRCULAR VELOCITY	INSERTION VELOCITY GREATER THAN CIRCULAR VELOCITY





ANSWERS TO REVIEW QUESTIONS (continued)

ANS-33: F Insertion angle (frames 2-11, 2-12, 2-13)

D Flight Path angle (frames 2-4, 2-5)

(G might also be considered correct, but it is technically the initial flight path angle, so D is a better choice.)

C True anomaly (frames 2-1, 2-2, 2-3)

ANS-34: circular (frame 2-9)

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